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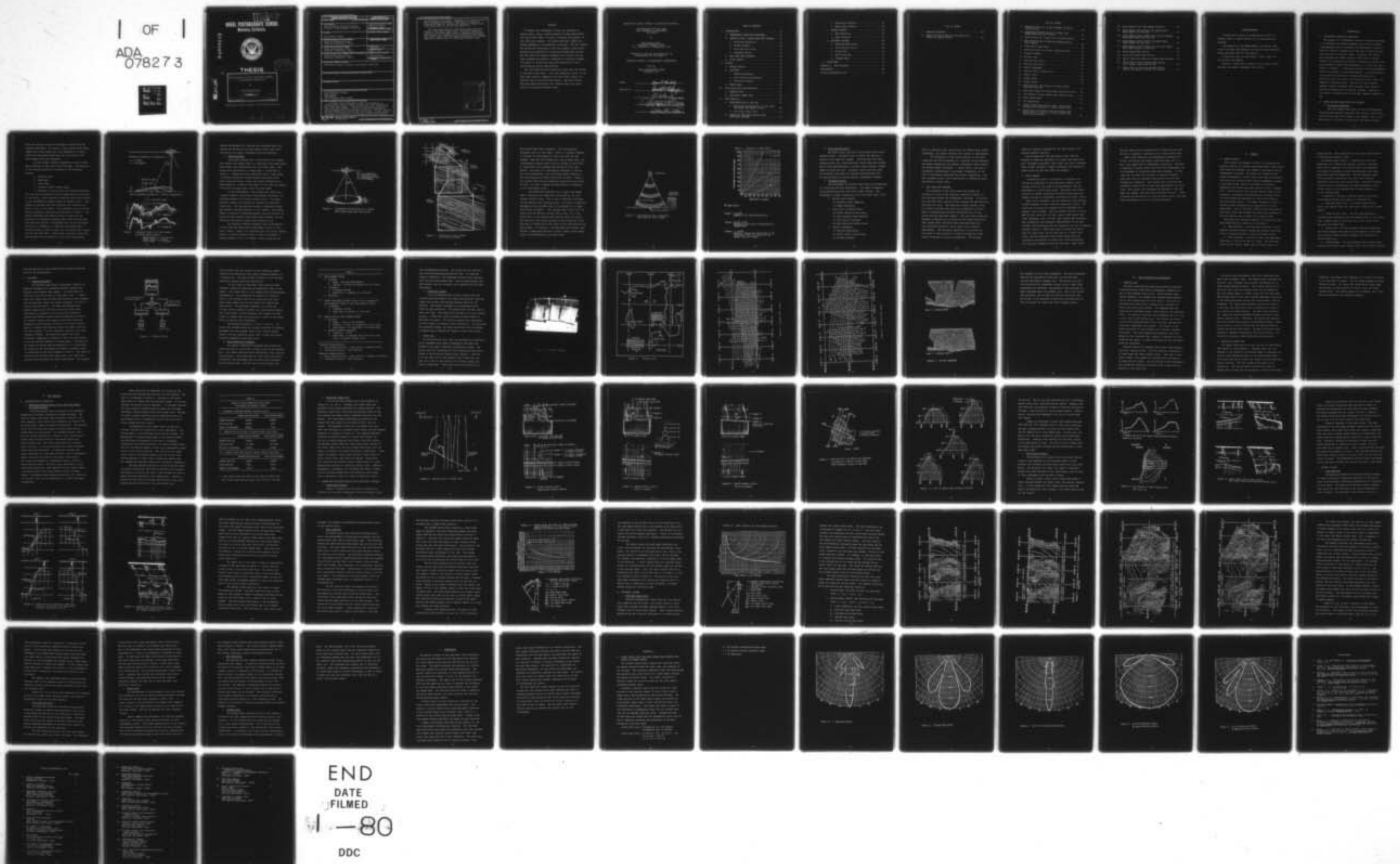

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THE EVALUATION OF DUAL BEAM ECHO SOUNDERS
IN HYDROGRAPHIC SURVEYING

by

Dean Robert Seidel

Sep ~~tember~~ 1979

Thesis Advisor: D. E. Nortrup

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A limited area hydrographic survey was conducted in shallow water, using a launch equipped to sound concurrently with three beam widths, in order to evaluate the benefits of dual beam echo sounders. The narrow beam echo sounder has become commonplace in hydrographic surveying. This has reduced the bottom area insonified by the echo sounder's beam, which decreases the probability of detecting navigational hazards.

The dual beam echo sounder, equipped with a narrow and wide beam, sounding concurrently, represents a relatively inexpensive means to increase the detection capabilities, while preserving the narrow beam operation.

The wide beams detected significant peaks that were absent on the narrow beam trace. The wider hyperbolic returns of the wide beams served to emphasize the narrow beam returns over features with little horizontal extent. The narrow versus wide beam depth differences over feature peaks were found useful in isolating the peak's apex.

ABSTRACT

A limited area hydrographic survey was conducted in shallow water, using a launch equipped to sound concurrently with three beam widths, in order to evaluate the benefits of dual beam echo sounders. The narrow beam echo sounder has become commonplace in hydrographic surveying. This has reduced the bottom area insonified by the echo sounder's beam, which decreases the probability of detecting navigational hazards. The dual beam echo sounder, equipped with a narrow and wide beam, sounding concurrently, represents a relatively inexpensive means to increase the detection capabilities, while preserving the narrow beam operation.

The wide beams detected significant peaks that were absent on the narrow beam trace. The wider hyperbolic returns of the wide beams served to emphasize the narrow beam returns over features with little horizontal extent. The narrow versus wide beam depth differences over feature peaks were found useful in isolating the peak's apex.

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The Evaluation of Dual Beam Echo Sounders in Hydrographic Surveying

by

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Lieutenant Commander, NOAA
B.S., University of Washington, 1969

Submitted in partial fulfillment of the requirements for the degree of

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from the

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I. INTRODUCTION

A. HYDROGRAPHIC SURVEYING PROCEDURES

The purpose of a hydrographic survey for nautical charting is to delineate the bottom topography and to detect hazards. A hydrographic survey is generally accomplished by running a series of parallel sounding lines with ten to twenty per cent crossing lines to provide a check. Typically, the initial main sounding line scheme indicates areas where a further reduction in sounding line spacing is required to define areas of particularly rough bottom topography, or to find the least depths of features. A substantial portion of the hydrographer's efforts is devoted to item investigations. An item investigation consists of proving or disproving existence of a particular object or feature and obtaining a least depth, for example, a submerged wreck. Detection of these features commonly requires extremely small sounding line spacing to achieve one hundred per cent bottom coverage. Coverage of this extent is impractical with the echo sounders commonly in use.

B. SURVEYING WITH NARROW BEAM ECHO SOUNDER

1. Horizontal Resolution

The echo sounder beam widths in use for hydrographic surveying have generally decreased over the past twenty years, and the narrow beam echo sounder is now common. This is primarily due to an effort to obtain the true depth directly below the survey vessel with the higher resolution of the narrower beam width. The thirty to sixty degree beam widths, common one or two decades ago, were ambiguous as to where within the insonified bottom area the least depth of the echo sounder trace had originated.

An echo sounder records a hyperbolic trace for each point reflector as the survey vessel proceeds. The character of the recorded hyperbola is affected by the following factors:

a. Speed of Vessel

b. Beam Width

c. Water Depth

d. Recorder's Paper Advance Speed

e. Recorder's Vertical Scale and Calibrated Velocity

The trace may be considered a sum of hyperbolas for each point on the bottom. These hyperbolic properties have been previously well documented by Krause (1962) and Hoffman (1957). True depths are recorded only while directly over the apex of a peak, or over a flat bottom. These properties and the characteristic hyperbolic equations are presented in Figure 1. The figure illustrates the relative error in depth, and the position of a sounding in shallow water, when only the beam width has been altered. The maximum error in the horizontal position of a sounding as a function of the beam width is $d(\cos(\theta))(\sin(\theta))$, where d equals the true depth, and θ equals one half the beam width. Narrow beam, vertically stabilized echo sounders of seven degrees or less have substantially

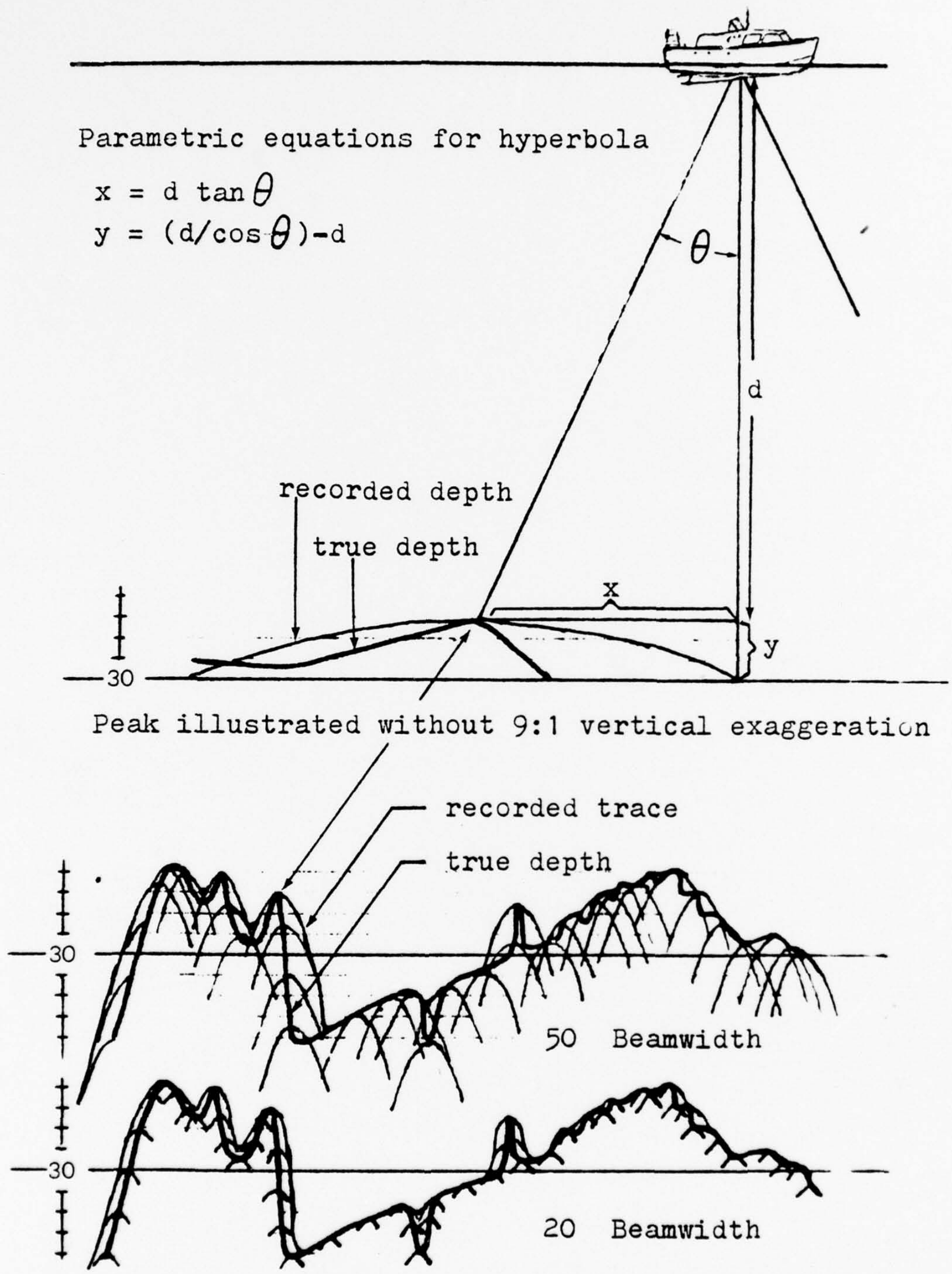


Figure 1 Idealized trace for a Echo Sounder in fairly Shallow Water

paper advance - 120 inch/hour
vessel speed - 8 knots
water depth - 30 fathoms

reduced the ambiguity by reducing the insonified area, and placing the position of recorded depths within limits more consistent with today's obtainable position accuracies.

2. Bottom Coverage

The bottom coverage over a flat bottom, for a simple cone shaped echo sounder beam, is a function of the beam width, water depth, pulse repetition rate, and vessel speed. The bottom area insonified by a single ping is illustrated in Figure 2. Assuming the pulse repetition rate is high enough to provide substantial overlap between insonified bottom areas along the vessel's track, the bottom coverage may be approximated by a swath of width equal to two times the tangent, of one half the beam width, times the water depth.

As the hydrographer's echo sounder has evolved into a higher frequency and narrower beam sounding instrument, an increased problem with bottom coverage arises. The narrow beam echo sounder has substantilly reduced the insonified bottom area. The line spacing required to adequately detect and delineate shoaling features is also reduced. The hydrographer's objective of detecting hazards, and the objective of high resolution accuracy using narrow beam sounders, are contradictive when using a single beam sounding system.

The problem of bottom coverage is well illustrated by a recent National Ocean Survey hydrographic survey in Cook Inlet, Alaska. Figure 3 is a position plot of a survey launch's efforts to confirm reported shoals of about six fathoms in sounding depths of 10 to 15 fathoms, using a seven and one

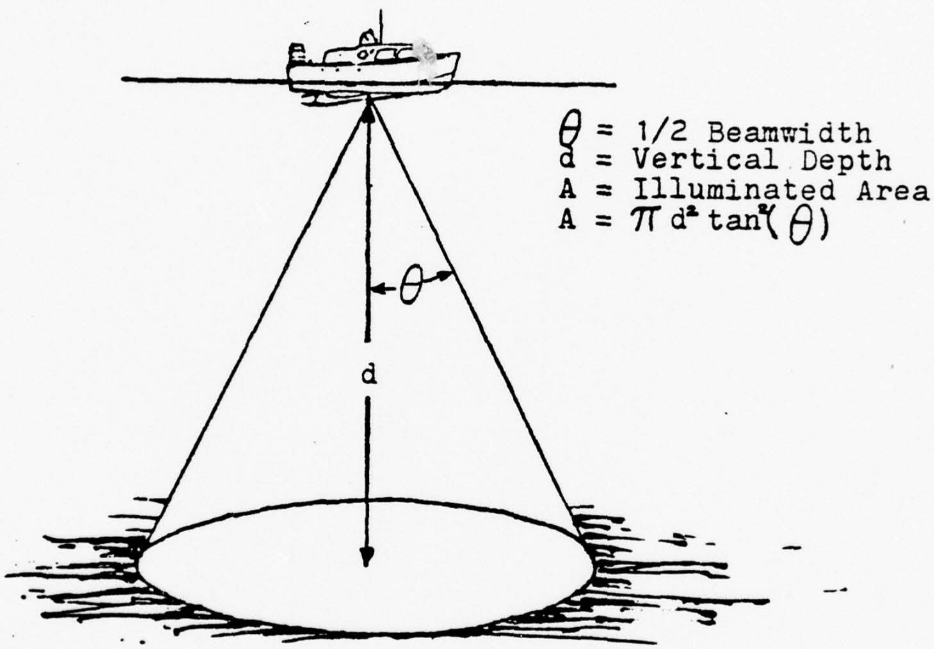


Figure 2. Illuminated Bottom Area for a simple Cone Shaped Beam over Flat Bottom

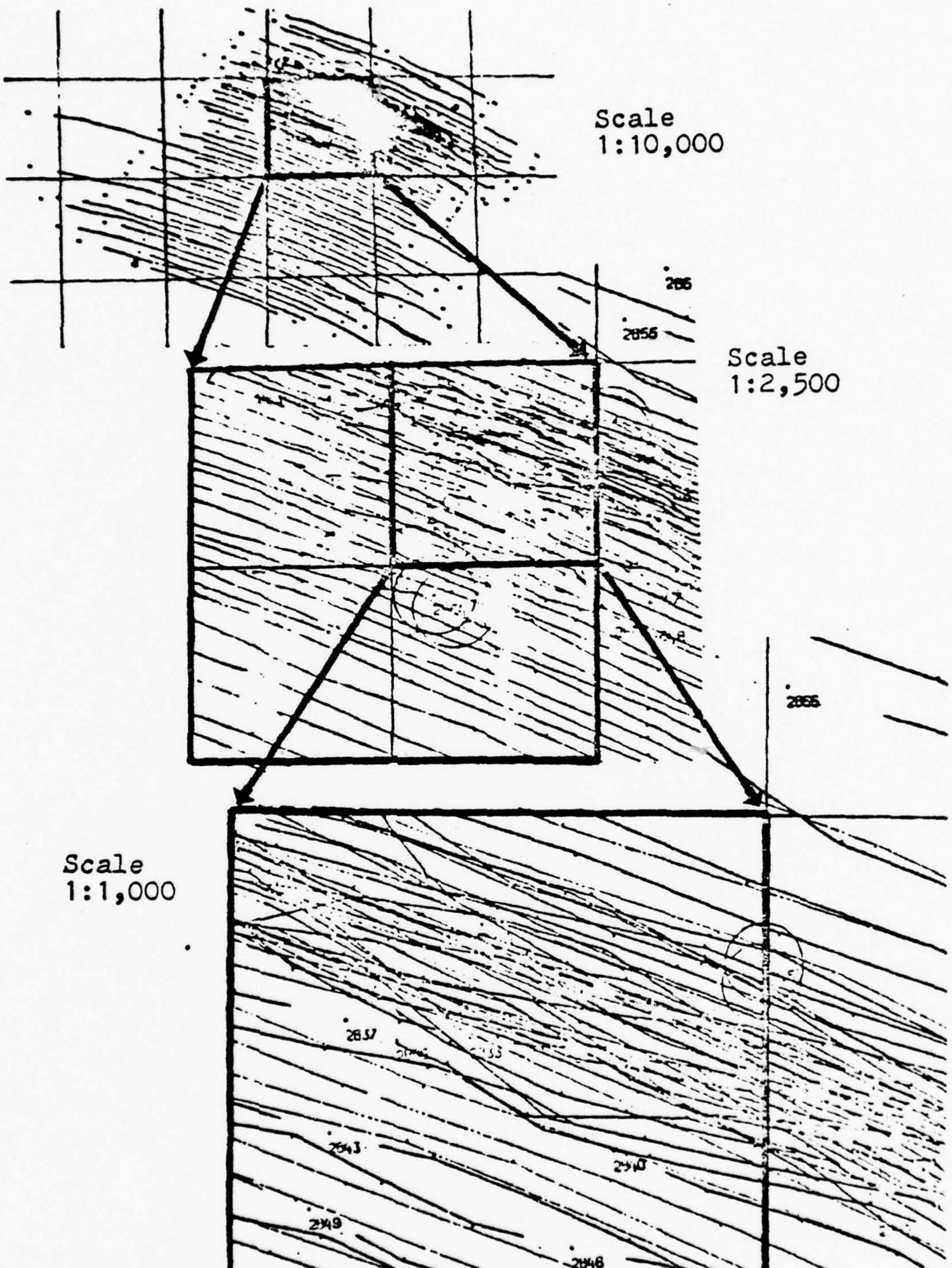


Figure 3 Position Plot of a Search for a Bottom Feature

half degree beam width transducer. The investigation eventually led to a wire sweep. There is a natural tendency to initiate an investigation of this type with the echo sounder. When the echo sounder has a narrow beam width, the investigation rapidly evolves into an attempt to cover fairly large areas with sounding line spacing of only a few meters. The result is a substantial investment of time by the field hydrographer, and a disproportionate increase in the time required to process and verify the data. Figure 3 was created from blow-ups originally requested by the survey verifier, in order to manage the high density of soundings in the investigation area.

The bottom area insonified by a simple cone shaped beam is naturally not completely illustrated by the echo sounder recorded trace. This is due to spherical spreading and stretching of the outgoing pulse. The effect of spherical spreading on the recorded trace is illustrated for a simple flat bottom in Figure 4. The recorded trace starts with the return from the shortest two-way travel time. For a flat bottom this is the vertical path directly below the vessel. The duration of the return develops as the curved wave front continues to return out to the limits of the beam and over the pulse length. In actuality, the wide beam echo sounder trace becomes a complicated function of pulse length, bottom topography, bottom penetration, and beam width.

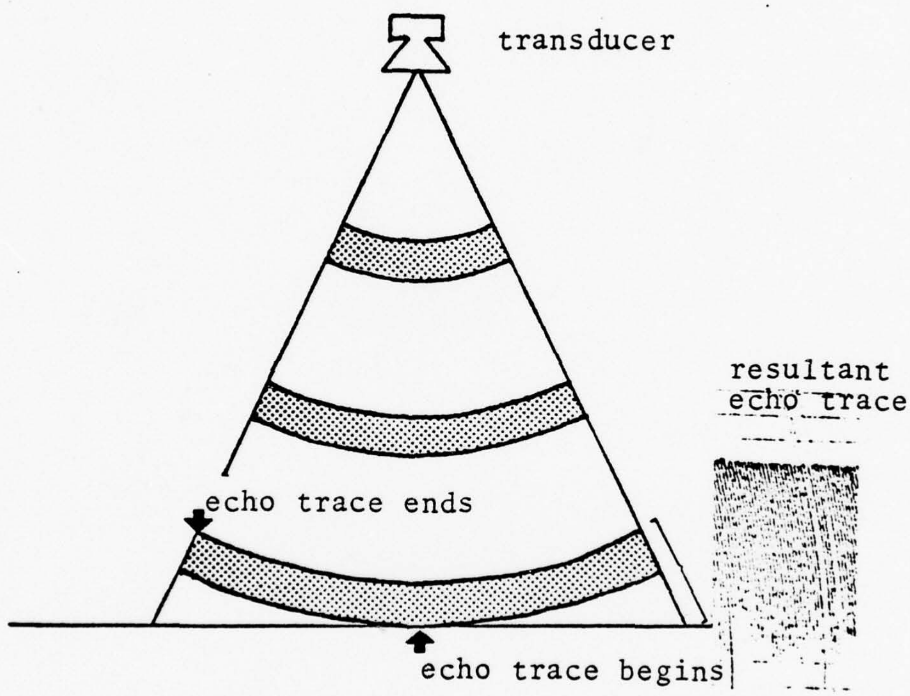
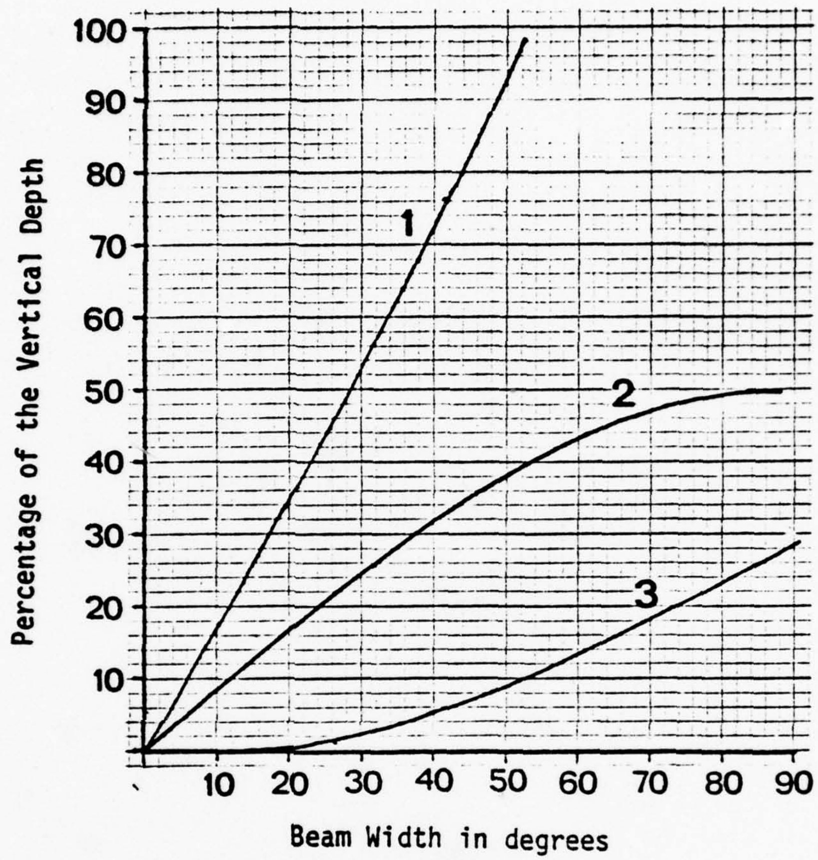


Figure 4. Echo Duration due to Spherical Spreading and Pulse Length

Figure 5. Functions of Beam Width



θ = Beam Width/2

Curve#1 - $2 \times \tan(\theta)$
Diameter of the insonified bottom area

Curve#2 - $\cos(\theta)\ \sin(\theta)$
Maximum horizontal error in the position of a recorded depth

Curve#3 - $1 - \cos(\theta)$
Height of a feature that may be hidden in the echo smear by spher ical spreading at the lateral limits of the beam.

3. Pitch and Roll Error

The heave, pitch, and roll of the survey vessel cause sounding errors. The heave error is nearly the same for a narrow or wide beam echo sounder. The pitch and roll cause pointing errors for a non-stabilized, narrow beam echo sounder, while a wide beam maintains a vertical return through a higher degree of pitch and roll. The heave, pitch, and roll error on an analog trace cannot be reliably differentiated from the analog record of similar periodic topographic features.

4. Frequency Factors

The development of narrower beam widths was accompanied by increasing operating frequencies. The higher frequencies facilitated narrow beam width echo sounder designs. The advantages of higher frequencies are listed below (Watt, 1977).

a. Shorter Pulse Lengths

(1) Shallower Depth Capability

(2) Higher Resolution

b. Lower Level of Ambient Noise

(1) Better Signal-to-Noise Ratio

(2) Lower Acoustic Power Required

(3) Less Noise on Echogram

(4) More Definitive Bottom Traces

c. Smaller Transducers

(1) Narrower Beam Widths

(2) Easier Launch Installations

(3) Portable Sounders

The list indicates that, particularly for shallow water launch hydrography, the higher frequency echo sounder is advantageous.

The attenuation of the sound intensity in the water column and the bottom sediments is a function of the frequency. The higher frequencies have greater attenuation, which reduces the maximum ranges obtainable. A second factor, that may be considered a disadvantage of the higher frequencies, is the loss of information concerning the bottom's composition. The high frequency allows little penetration or information below the bottom's surface layer.

C. DUAL BEAM ECHO SOUNDERS

The acceptance of the narrow beam echo sounder has resulted in a loss of the inherently beneficial factors of the wide beam systems for hydrographic surveying. In particular, the wide beam's greater bottom coverage and peak detection abilities were lost. Dual beam echo sounder systems, which are readily available and relatively inexpensive, provide a means of combining the desirable characteristics of both narrow and wide beam echo sounders. The dual beam systems are designed to operate with a narrow and wide beam concurrently. Some systems offer selectable beam width operation only, vice concurrent operation, which limits their potential considerably. The concurrent operation of the narrow and wide beams is made possible by using two frequencies sufficiently different to prevent interference. The recorded traces are typically displayed on the same recorder with separate darkness controls.

Various means have been developed to deal with the problems of spherical spreading in a simple wide beam (side scan, outrigged transducers, multi-beam, and sector scanning). These systems represent a higher technology, and typically a higher price tag than dual beam echo sounders.

D. PRIOR STUDIES

A substantial amount of literature is available concerning the properties of wide beam echo sounders, their recorded effect on the shape of bottom features, and the advantages of a narrow beam system. References that relate directly to studies concerning the usage of dual beam echo sounders systems in hydrographic surveying are fairly scarce.

Weeks (1971) discusses a survey conducted in the Marshall Islands designed to find a route for underwater cables. The survey was in an area of irregular bottom topography with numerous coral outcrops. The echo sounder used was an ATLAS-DESO AN 6014, which has a 30 kHz, twenty-eight degree beam width transducer, and a 210 kHz, eight degree beam transducer. Both frequencies were displayed simultaneously on the same recorder, and differentiation was obtained by the use of separate grayness controls. Weeks found that by setting the narrow beam to a dark trace, and the wide beam to a lighter gray trace, the high resolution narrow beam bottom trace was continually discernible as a dark line, while maintaining the side echo information from the wide beam. Weeks found the dual beam system a vaulable aid for detecting the coral outcrops as opposed to operating with a single narrow beam.

Cohen (1959) discusses the simultaneous operation of a 34 kHz, six and one half degree stabilized beam, and a 12 kHz, sixty degree beam in hydrographic operations. The paper is generally oriented toward deep water ship hydrography, and the advantages of stabilized narrow beam sounding. In this study the two beams were recorded on separate recorders. A deep water area was contoured using narrow and wide beam sounding for comparison. The contour plot illustrated the substantial depth errors in deep water generated by the wide beam. The features were broadened and smoothed by the wide beam echo sounder, and small scale features were lost. Cohen discussed the possibility of using the narrow versus wide beam depth differences as an aid in ship positioning.

II. PROJECT

A. PROJECT DESIGN

This project was designed to assist in evaluating any possible benefits or problems encountered while using various beam width and frequency echo sounders concurrently during hydrographic surveying. The design was oriented toward launch hydrography in shallow water (less than 100 fathoms). The project was directed toward launch hydrography, because a dual beam system, which is considered a relatively inexpensive and partial solution, applies better to launch work. The multi-beam, swath systems require space for the processors, peripherals and mounting the transducer array. The installation and operation of a dual beam system is relatively much simpler. The higher technology systems to increase bottom coverage will be adopted first by ship hydrography. Most of the prior study work has been done in deep water, where the problems with spherical spreading of the wide beam are not as severe as in shallow water.

The project was designed primarily to evaluate the dual beam system abilities relative to two factors:

1. Peak Detection - The wide beam of the dual system provides increased bottom coverage and increases the probability of detecting shoals of small horizontal extent.

2. Peak Isolation - The narrow versus wide beam depth difference is zero on the apex of a peak. The wide beam always records shoaler depths than the narrow beam on a

sloping bottom. This characteristic of a dual system assists in locating the feature's apex.

To evaluate these factors, a limited area survey was undertaken at a reduced line spacing, relative to National Ocean Survey standards, to delineate small scale features. The launch was equipped to sound simultaneously with three beam widths and two frequencies. The peak detection capabilities would be measured by the small scale features detected by the wide versus narrow beams. The peak isolation abilities would be measured by the depth differences, wide versus narrow, as the sounding lines crossed adjacent to, or over feature peaks.

In addition to the major interest factors cited above, the following factors were subject to consideration:

1. Wide Beam Depth Error - The narrow beam provides nearly true depths, while the wide beam is affected by bottom slopes.

2. Pitch and Roll Error - The wide beam maintains a recorded depth originating from the perpendicular to the bottom over a higher degree of pitch and roll of the survey vessel than does the narrow beam.

3. Bottom Type - The low frequency wide beam penetrates the bottom sediment more than the high frequency narrow beam. This indicates bottom acoustic impedence and correlates to bottom composition.

4. Minimum Range - The high frequency narrow beam system typically has shorter pulse lengths than a low frequency system,

allowing operation in very shallow water without losing the trace in the reverberation.

B. EQUIPMENT

1. Sounding Equipment

The National Ocean Survey hydrographic launches are generally equipped with automated surveying systems that include a seven degree echo sounder. All beam widths are referred to the six db down, or half power level. A twenty-eight foot launch from the NOAA ship RAINIER had been equipped with an additional twenty-two degree transducer to assist in locating reported shoals. The NOAA ship RAINIER subsequently requested the seven and twenty-two degree beam transducers be designed to allow concurrent sounding to evaluate the benefits during various hydrographic projects. The launch's regular seven degree narrow beam system was equipped by the Electronics Division of the Pacific Marine Center to display the seven and twenty-two degree traces on the same recorder. The two transducers operate at the same frequency (100kHz). The twenty-two degree beam width transducer triggering was delayed by about six milliseconds, or two and one half fathoms of recorded depth. The delay for the twenty-two degree beam was generated at its transceiver. The design of the seven degree and twenty-two degree system is illustrated in the block diagram of Figure 6. The digitizer received only from the seven degree beam. The launch processing system recorded only narrow beam depths. The outgoing

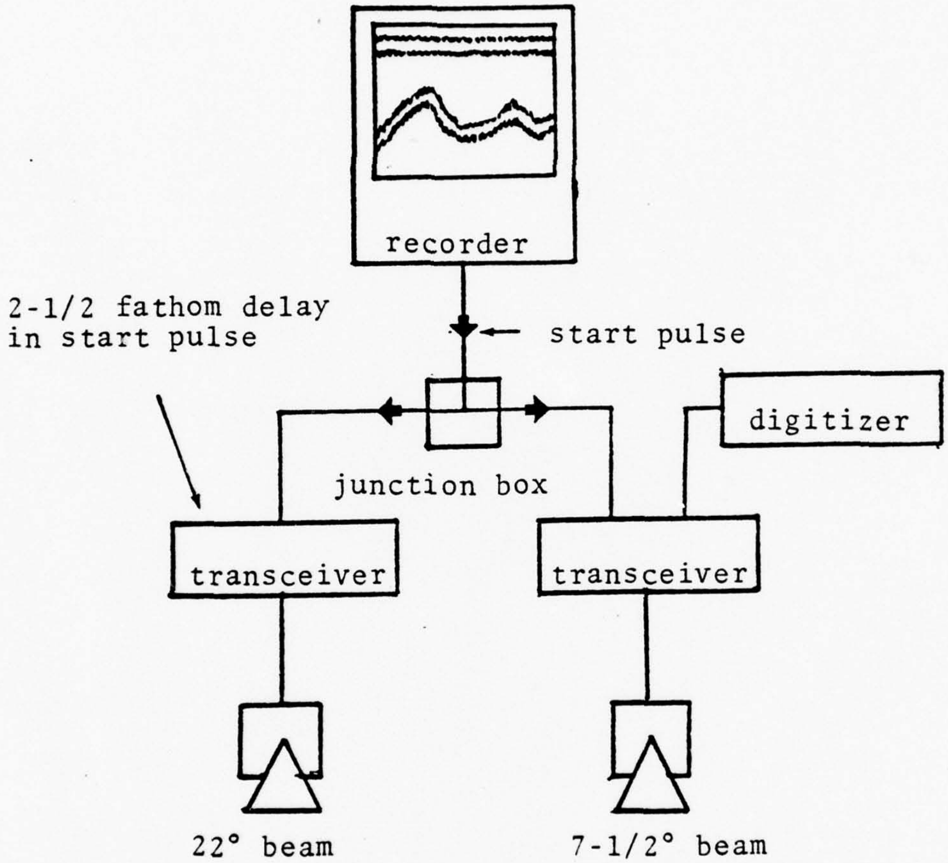


Figure 6. Sounding System.

"start" pulse from the recorder and the returning signals from the two transceivers were simply connected together at a junction box. The gain and mark intensity of the recorder controlled signals from both transceivers.

For the study, an additional wider beam and lower frequency system was requested and temporarily added to the launch. This twenty-five by sixty degree beam system operated independently. The transducer was mounted on a portable strut on the starboard side of the launch with the sixty degree beam athwart-ship and the twenty-five degree beam fore and aft. The operating frequencies of 21 kHz and 100 kHz differed enough to prevent any interference problems. This system added a second frequency and extended the beam width to a degree that was envisioned as closer to the useful limits in shallow water hydrography.

The sounding equipment is listed in Table 1. The project was designed using the existing inventory of sounding equipment from the National Ocean Survey, Pacific Marine Center, with the underlying desire that a useful and readily available permanent system might exist.

2. Data Acquisition Equipment

The launch's "Hydroplot" automated data acquisition system was used to collect and initially plot the hydrographic data. The system collected narrow beam depths, time, position and correctors. The corrections for tide, draft and control calibrations were performed, and the narrow beam soundings were plotted on-line. The data were stored on paper tape

TABLE I

* A. SEVEN DEGREE SYSTEM

1. Recorder
   a. Range - 400 feet/200 fathoms
   b. Phasing - 100 feet/50 fathoms per 6.5" Scale
2. Transducer
   a. Frequenty 100 kHz
   b. Beam width 7.5 degrees to 6 db level
3. Digitizer

- -

* B. TWENTY-TWO DEGREE SYSTEM (consists of a transceiver and transducer added to the seven degree system)

1. Transducer
   a. Frequency 100 kHz
   b. Beam width 22 degrees to 6 db level

- -

**C. TWENTY-FIVE BY SIXTY DEGREE SYSTEM

1. Recorder
   a. Range - 1 foot to 250 fathoms
   b. Phasing - 50 feet or fathoms per 6-1/4" scale
   c. Chart speed - 60 inches/hour, 120 inches/hour
2. Barium Titanate Transducer
   a. Frequency - 21 kHz
   b. Beam width - 25 degrees fore and aft to 6 db level, 60 degrees athwart ship

---

* General Characteristics

1. Pulse repetition rate - feet (6/sec.), fathoms (2/sec.)
2. Calibrated velocity - 4800 feet/sec.

**General Characteristics

1. Pulse repetition rate - feet (10/sec.), fathoms (1-2/3/sec.)
2. Calibrated velocity - 4800 feet/sec.

with accompanying printouts. The system was also used for the initial editing and plotting off-line. By using the launch's "Hydroplot," the soundings collected were received only from the seven degree beam. The wide beam analogs were hand scanned, and the printouts were annotated with the wide beam depths.

3. Artificial Targets

A set of three portable acoustic targets were constructed from high density one-eighth inch masonite, with one-eighth inch plastic foam packing material pasted to the surfaces. The bubbles entrapped in the packing material served as good reflectors. The targets were two feet wide by three feet high. The targets were designed to be just slightly buoyant, so that they could be placed at known depths by hand from the launch. The acoustic targets were constructed to serve crudely as sounding system calibrators. The objectives were determine whether the three beam widths were performing as expected and to measure the degree of side echo returns.

C. SURVEY AREA

The field work for this study was performed in conjunction with a navigable area survey, conducted by the NOAA ship RAINIER in the area of Auke Bay, Southeastern Alaska. The survey areas are illustrated by the following position plots, Figures 9 and 10 and the project area, Figure 8. Area One is in the small bay at the southeast end of Auke Bay, and Area Two is west of the southern end of Spuhn Island, and north of Gibby Rock. These areas were pre-selected due to

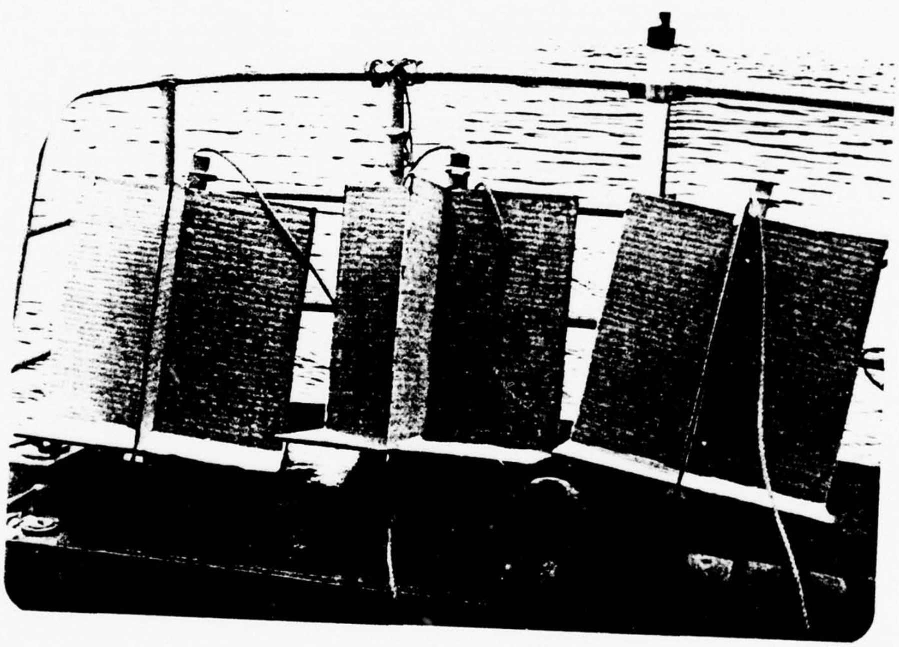


Figure 7. Acoustic Targets

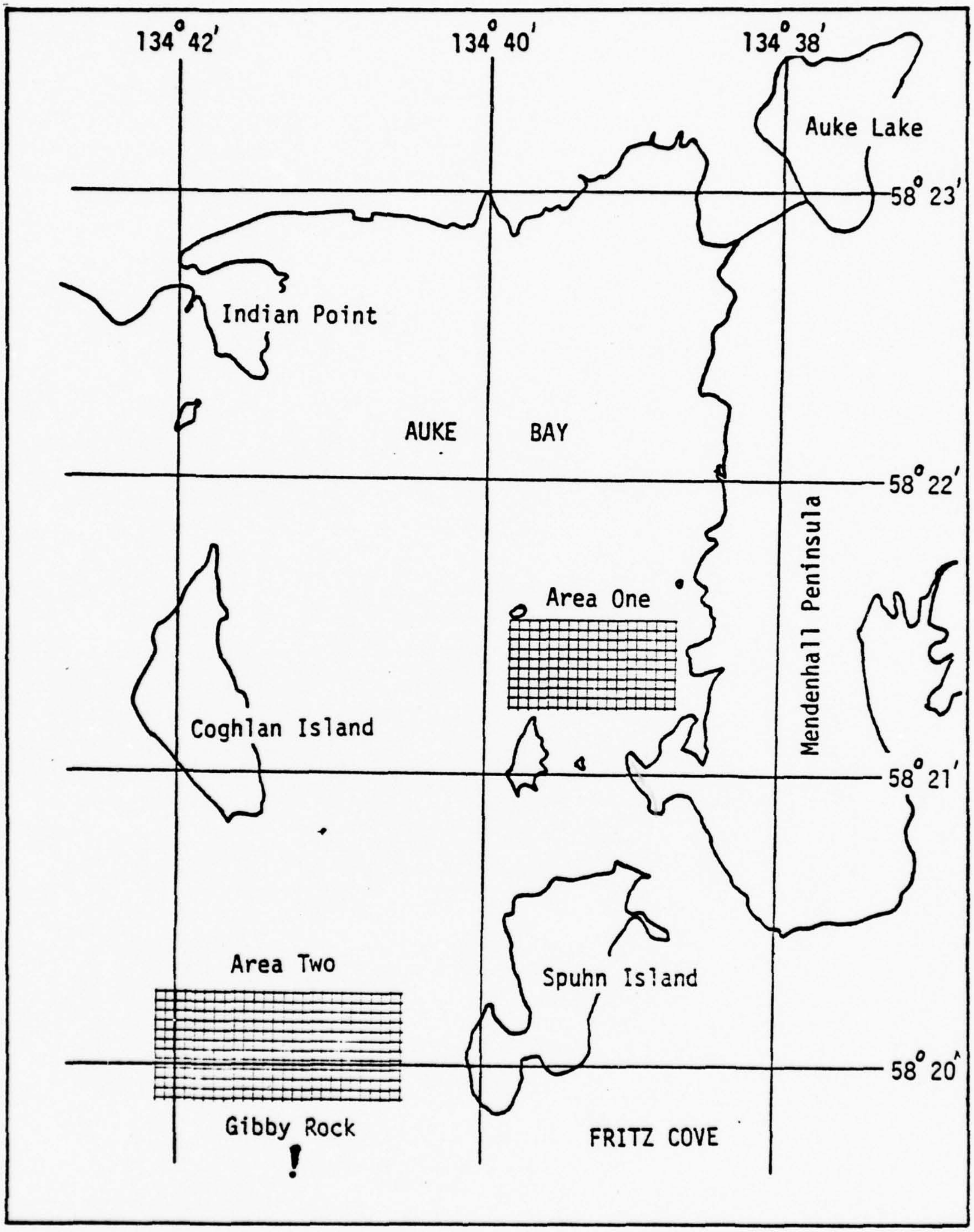


Figure 8. Project Area

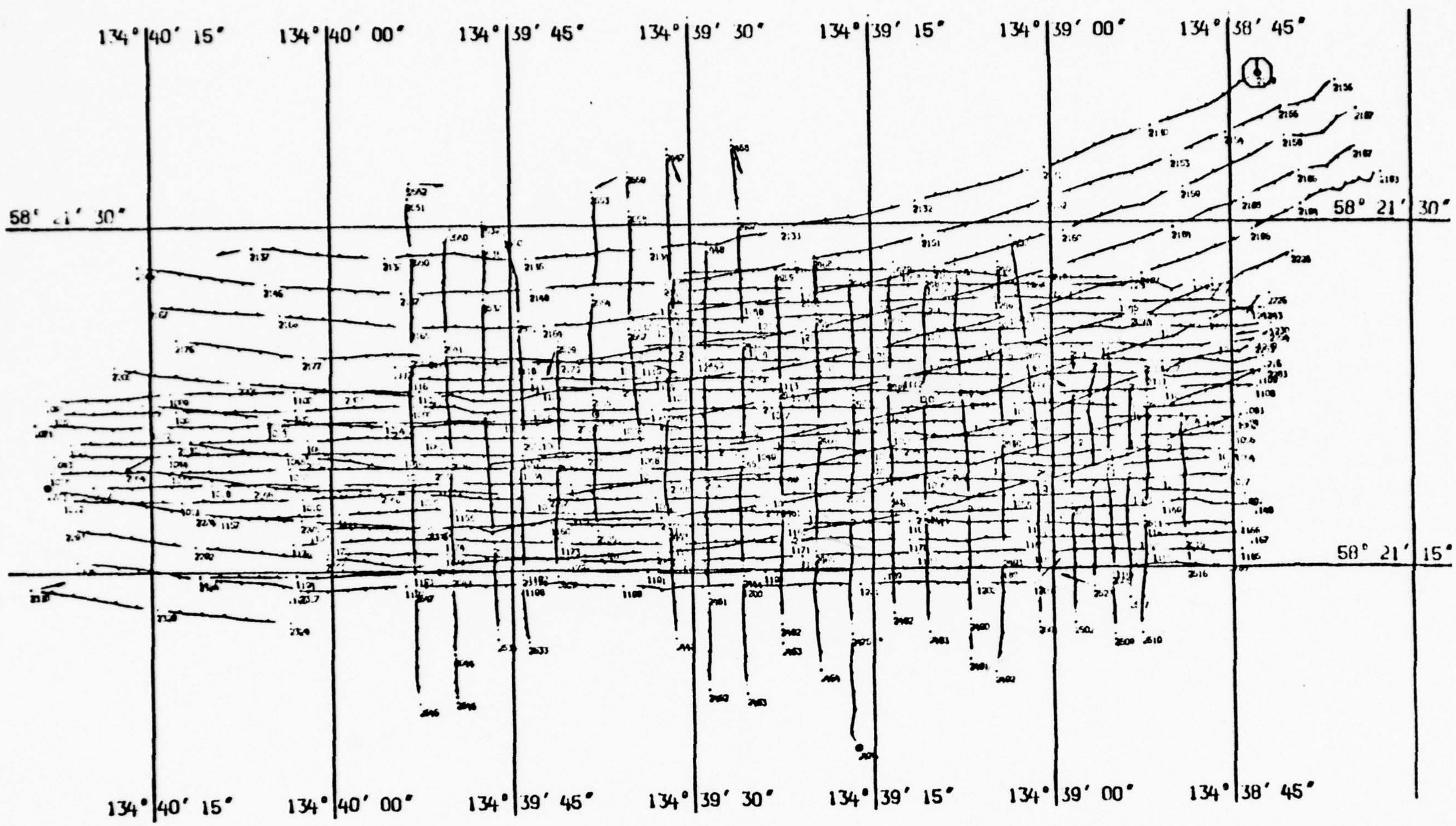


Figure 9. Position Plot Area 1

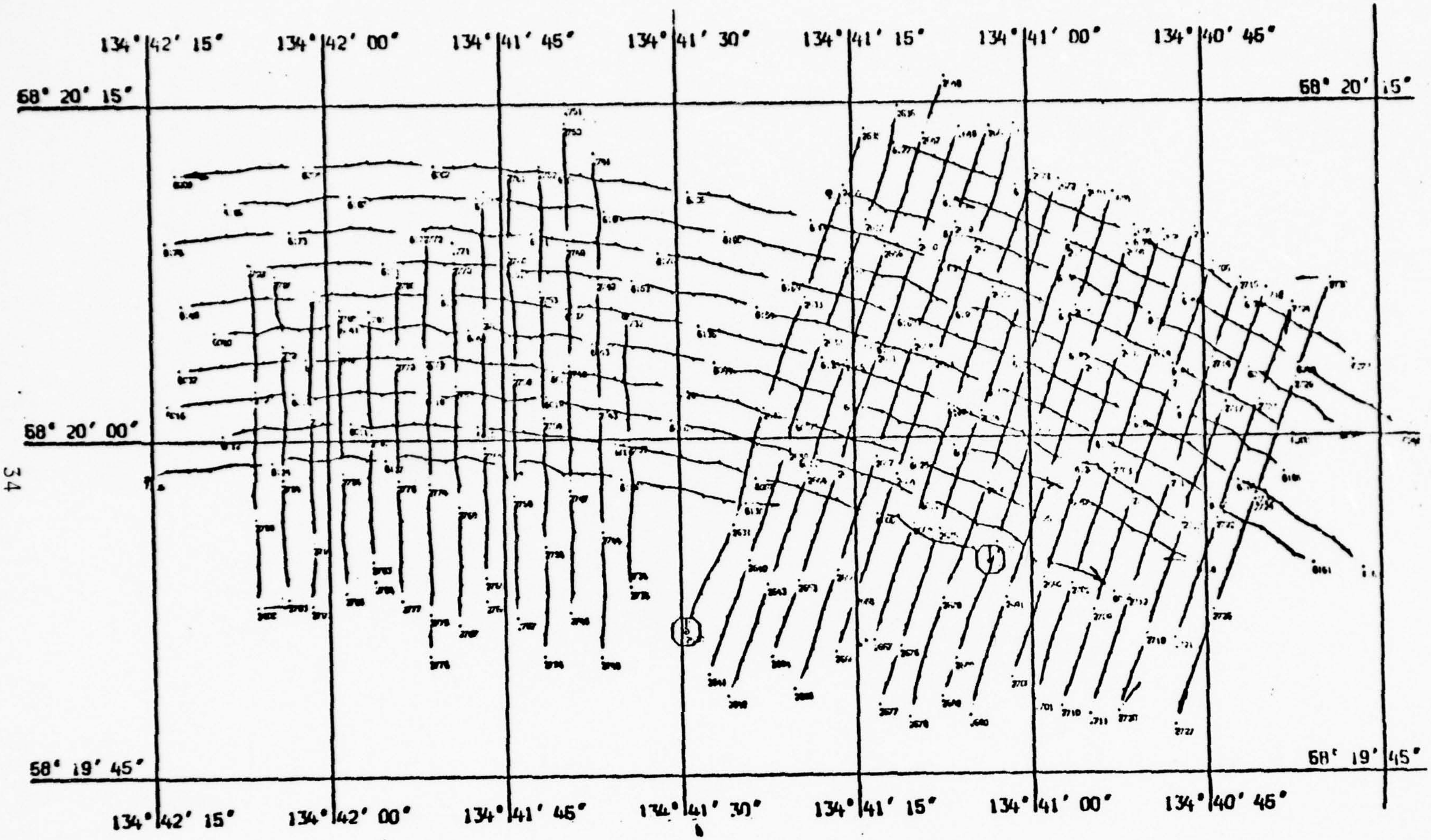
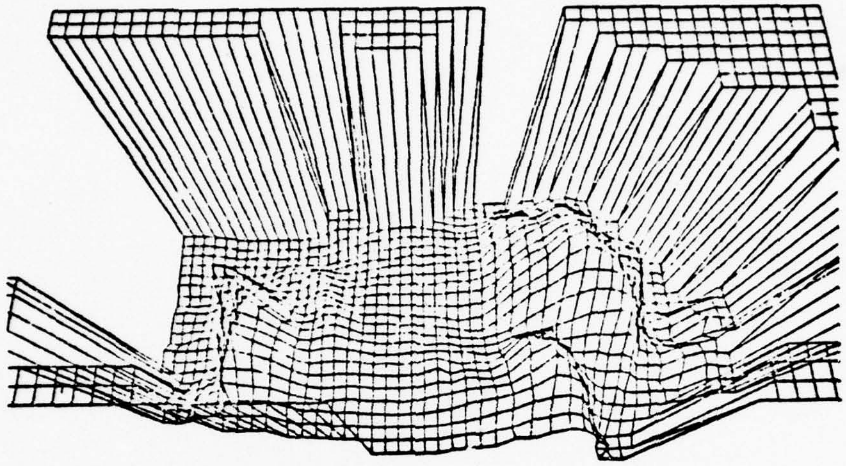
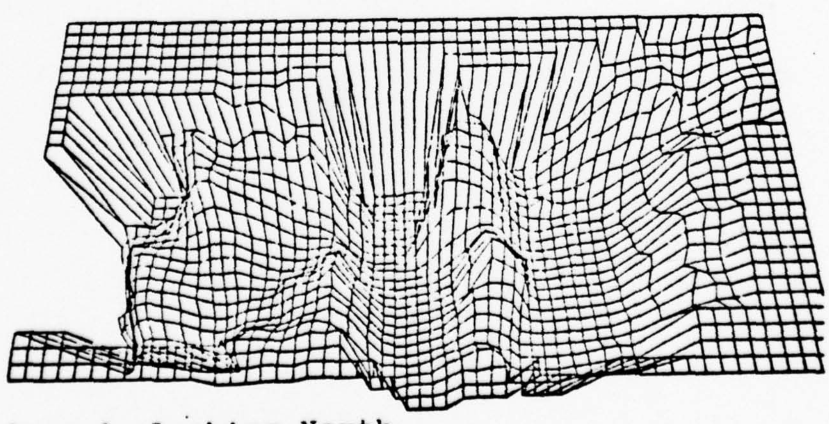


Figure 10. Position Plot Area 2



Area 2 Looking North



Area 1 Looking North

Figure 11. Bottom topgraphy

the roughness of the bottom topography. The area surrounding Auke Bay has been heavily glaciated, and the bays have received substantial sediment fill. The result is an area with extensive flat sedimentary bottom, fairly steep slopes approaching the shoreline, and generally large outcrops and peaks extending above the sediment fill. Due to the limited time available, and in order to avoid the relatively flat bay basins, it was necessary to pre-select working areas in which to operate the three beam width sounding system.

III. DATA COLLECTION AND PROCESSING

A. SOUNDING DATA

The data collecting and processing procedures generally followed National Ocean Survey hydrographic standards for a one to five thousand scale survey. Using National Ocean Survey standards, the sounding line spacing deemed appropriate for the working areas was fifty meters. Area One was developed with twenty meter sounding lines, and Area Two with a forty meter grid pattern. The sounding data were corrected for transducer draft, sound velocity, and predicted tides. The velocity correctors were determined by S.T.D. and C. T.D. casts in the survey area. The velocity was fairly close to the calibrated 4800 ft/sec. velocity, and velocity correctors' magnitudes were minimal. Bar checks, at one fathom intervals to seven fathoms, were carefully observed twice daily. The sixty degree beam transducer, which was mounted on the starboard side, required a separate bar check alongside the launch, in order to maintain the bar vertically below the transducer.

Position control was obtained from a super high frequency electronic ranging system. Area One contains a combination of range-range and range-azimuth control. Area Two is total range-azimuth. The azimuth was obtained from a theodolite of known position ashore. The positioning system transponders were calibrated morning and evening, using a known position adjacent to the study area.

The narrow beam hydrographic data were transferred from paper tape to magnetic tape. The magnetic tape contained the position, time, sounding, and corrector information for an eight second sounding interval. The original intent was to edit this tape, with the sounding data from the twenty-two and sixty degree beams, to create a data file for each beam. Then contour plots of the area's bottom topography, and plots of the depth differences between the various beams, could be automated. The eight second sounding interval was found to be too long, and would only create a generalized picture of the effects over large features. The small scale features, and significant depth differences between the beams at peak apexes, would be lost. Therefore, the narrow beam sounding data were plotted and contoured using automated means. These plots served as a basis for plotting the depth differences between the various beam widths. The depth differences were obtained by manually scanning the three analog traces, with particular attention to peak detection and peak apexes.

B. ARTIFICIAL TARGET TEST

The targets were fixed to a line, and set at known depths. (See Figure 12, Data Analysis.) Sounding lines were run adjacent to the targets at decreasing ranges to determine the relative side-looking abilities of the various beam widths. The initial plan was to anchor the targets in the working area before surveying. This was attempted and proved to be impractical. The size of anchor and buoy that could be handled from a launch did not guarantee a vertical wire angle.

Therefore, the targets were suspended on a line off the stern of the ship while at anchor. The wire angle remained vertical during the tests. The launch was controlled by range-range positioning, and the swing of the ship's stern, by visual sextant fixes. This method appears to be awkward, but it was the most expedient, and served the purpose.

IV. DATA ANALYSIS

A. CHARACTERISTICS OF THE DATA

1. Operating Characteristics of the Seven and Twenty-Two Degree Systems

A dual beam system usually operated at two different frequencies to prevent interference between the beams. The seven and twenty-two degree beam transducers operate at the same frequency, which allows both transducers to receive from the seven and/or twenty-two degree transmissions. The recorded traces from the seven and twenty-two degree beams did not perform quite as anticipated. The intended recorder trace, with the system connected as in Figure 6, was a seven degree bottom trace followed shortly by the delayed twenty-two degree bottom trace. The actual characteristics recorded were as follows. At low gain settings both traces reflected narrow beam characteristics. At high gain settings both traces converted to a wide beam character, and at intermediate gains, the traces were narrow with fainter wide returns. The system was operated at intermediate gains to retain a narrow and wide trace. The first trace consisted of a dark seven degree beam line, super-imposed with the lighter twenty-two degree receiver trace which became visible on bottom slopes. The delayed trace appeared essentially as a duplicate of the first trace, but was generated by a twenty-two degree transmission.

These traces may be explained, if the gain of the narrow and wide transceivers were not very well matched. The logic is illustrated in Table II. The gain of the narrow beam system was higher than the wide beam system. At low gain settings the narrow receiver dominates. At high gain settings the wide receiver's bottom return overcomes the recording thresholds, and the delayed wide trace becomes wide. But now, the narrow transmit and wide receive combination were at a high enough level for transmitted narrow beam side-lobes to return through the wide receiver.

An examination of the signal excess at high gain settings confirms the feasibility of this explanation. The average depth in the operating area was thirty fathoms. The manufacturer's maximum design depth is two hundred fathoms. The difference in propagation losses due to spreading, attenuation, and bottom backscatter for thirty fathoms versus that for two hundred fathoms, results in an approximate signal excess of plus thirty-seven db. This thirty-six db signal excess level on the narrow transmit and wide receive beam pattern generates a twenty-four to twenty-six degree beam. The computations and beam patterns are included in Appendix A.

The gain and mark sensitivity of the seven and twenty-two degree transceivers were both controlled at the recorder. Unfortunately, while in the field, little attempt was made to adjust the gain separately at the transceivers. Feasibly, a darker wide beam trace could have been obtained, while still maintaining the visibility of the narrow beam trace.

TABLE II

RESULT OF GAIN MISMATCH ON THE SEVEN AND TWENTY-TWO DEGREE SYSTEM

I. ORIGINALLY EXPECTED RESULTS (Matched Gains)

	NARROW BOTTOM RETURN	WIDE BOTTOM RETURN
NARROW RECEIVER	NARROW	NARROW
WIDE RECEIVER	NARROW	WIDE
RESULT TO RECORDER	NARROW	WIDE

II. RESULTS LOW GAIN (Gain of Narrow Higher than Wide)

	NARROW BOTTOM RETURN	WIDE BOTTOM RETURN
NARROW RECEIVER	NARROW	NARROW
WIDE RECEIVER	NO TRACE	NO TRACE
RESULTS TO RECORDER	NARROW	NARROW

III. RESULTS HIGH GAIN (Gain of Narrow Higher than Wide)

	NARROW BOTTOM RETURN	WIDE BOTTOM RETURN
NARROW RECEIVER	NARROW	NARROW
WIDE RECEIVER	WIDE	WIDE
RESULT TO RECORDER	WIDE *	WIDE

* A plus thirty-seven db level on the narrow transmit and wide receive beam pattern allows wide return to recorder.

2. Artificial Target Test

A few of the echo sounder traces are presented in Figures 13, 14, and 15. Sounding line number eight was obtained as the launch approached the targets head-on. The hyperbolic return has a distorted and extended width in this case because the launch slowed to maneuver directly over the targets. The seven degree beam began to digitize on the targets when the launch was stationed directly over the targets. The hyperbolic return for line numbers four and seven were obtained at a constant vessel speed, and the computed hyperbola is included in Figure 14. The computed hyperbola indicates horizontal extent for various beam widths, and assists in indentifying main beam versus side-lobe returns. The maximum lateral range for significant target returns for the seven, twenty-two, and sixty degree beam widths were two meters, ten meters, and twenty-two meters, respectively. These ranges correspond to slant range returns at beam widths of seven, thirty-three, and sixty-five degrees, respectively. This indicates the relative lateral signal levels at intermediate gain settings in relatively shallow water. Spherical spreading is illustrated in line number four where a target two and one half fathoms above the bottom has just become lost in the bottom trace at a range of twenty-two meters.

B. NARROW AND WIDE BEAM SOUNDING OVER INDIVIDUAL FEATURES

1. Large-Scale Features

Figure 17 displays the forty meter sounding line profiles over an eleven fathom peak from the northeast corner

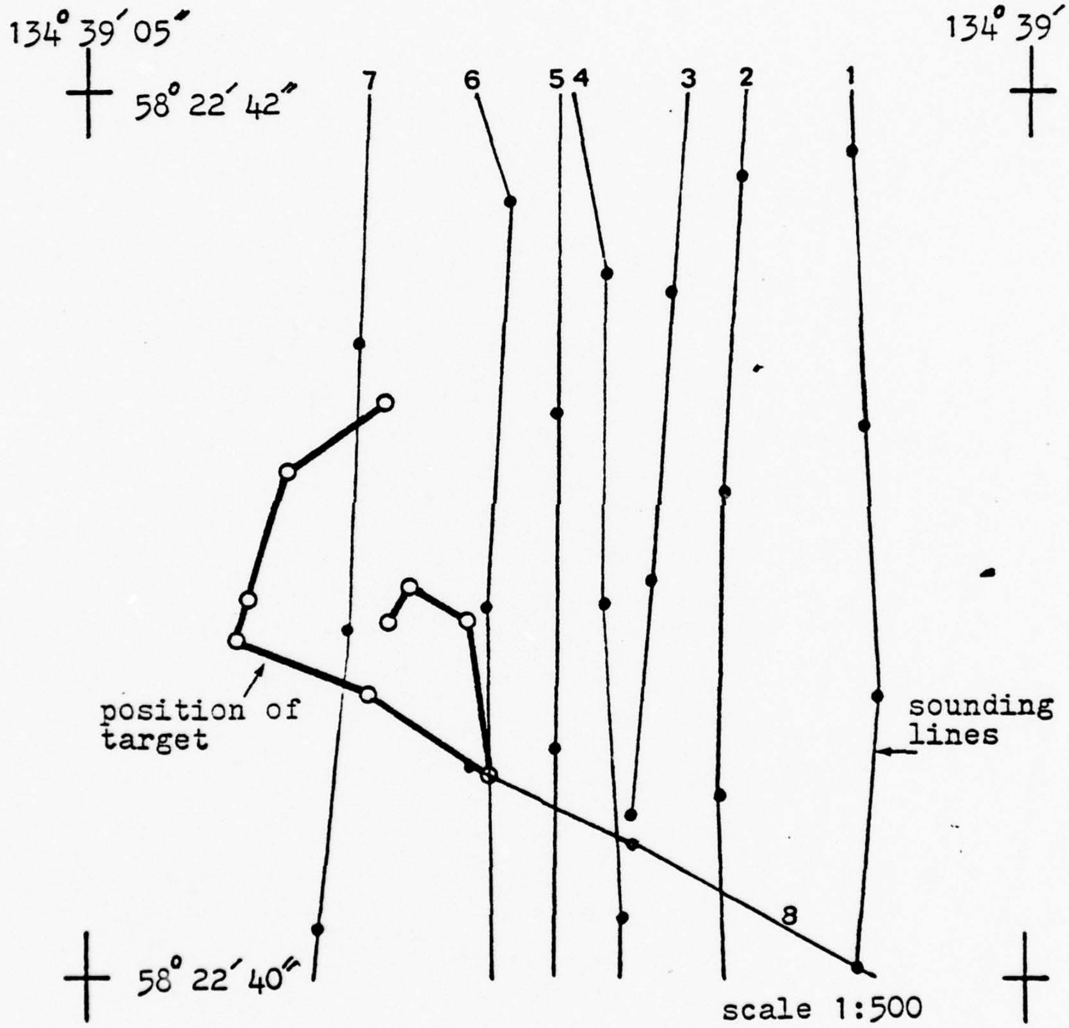
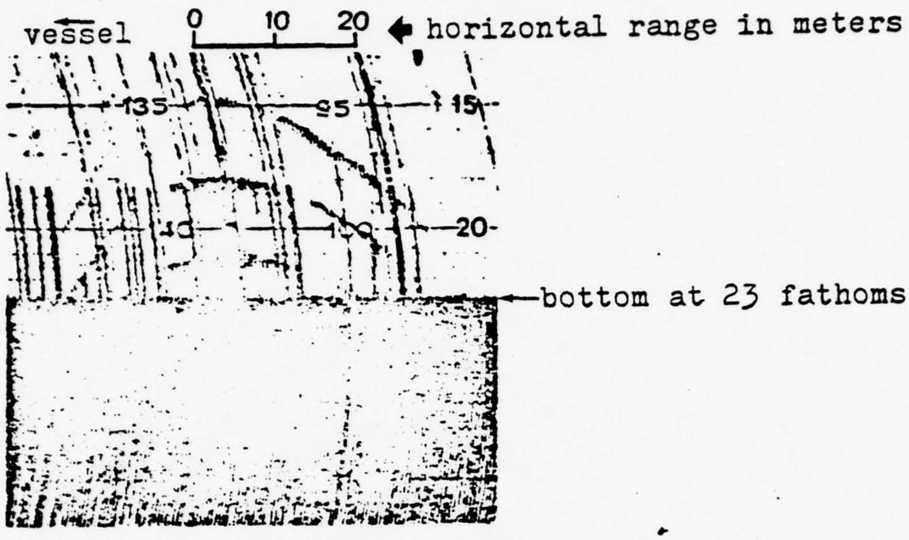
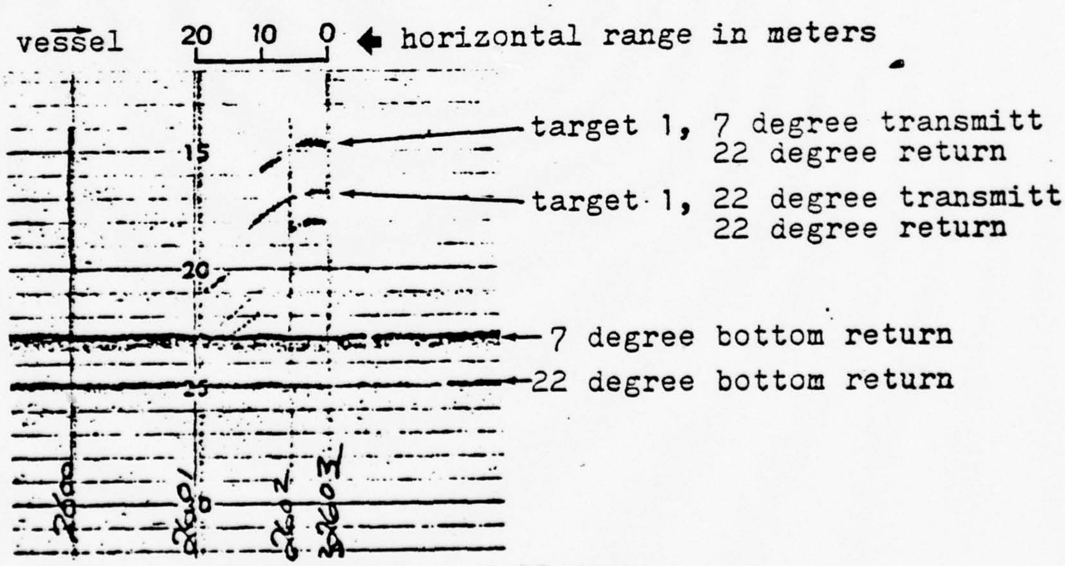


Figure 12. Position Plot of Target Test



Beam Width - 25 degree fore and aft
60 degree athwart-ship



Beam Width - 7 degree and 22 degree
conical

Figure 13. Target Traces, Line 8
Approaching Targets Head-on

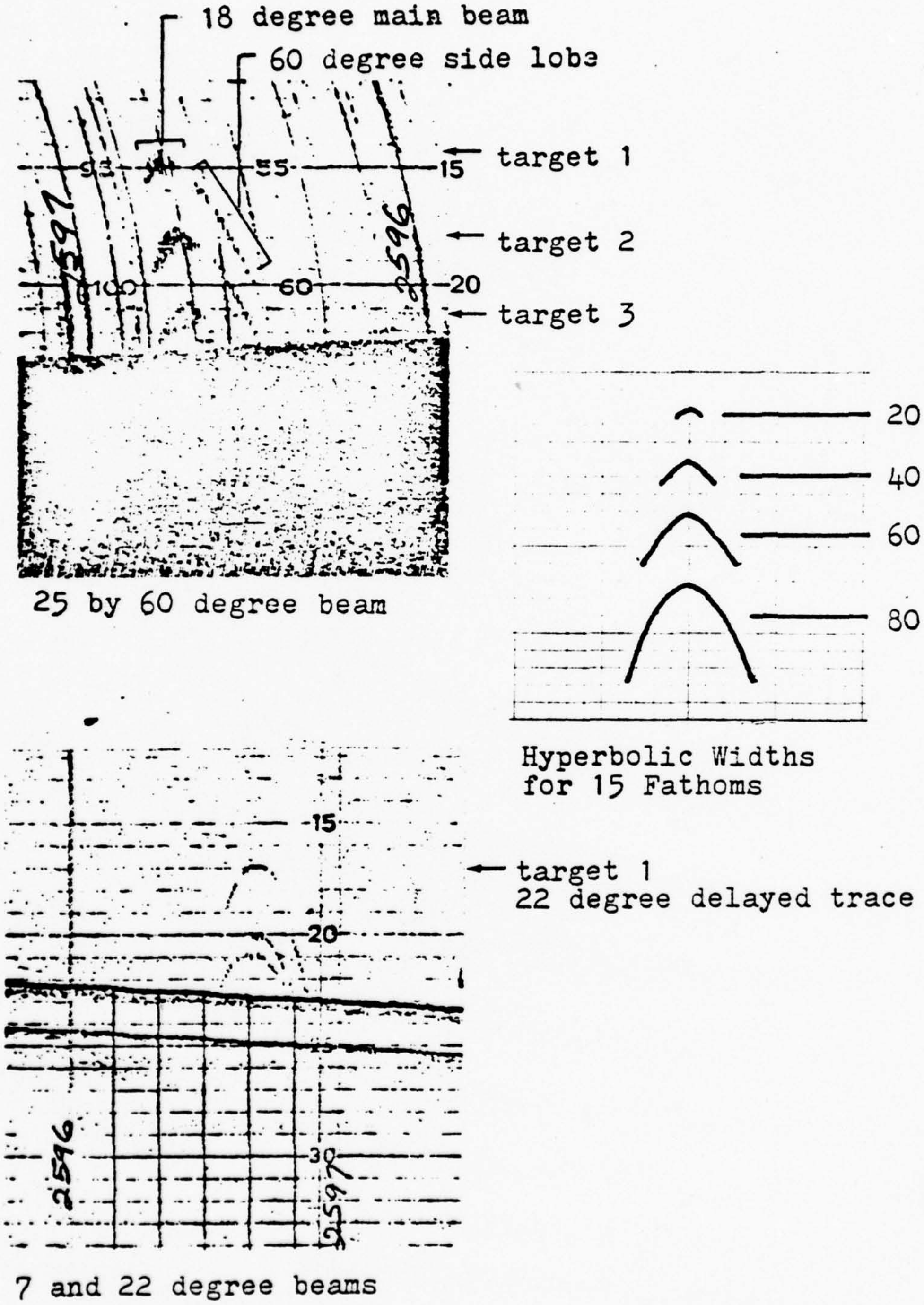
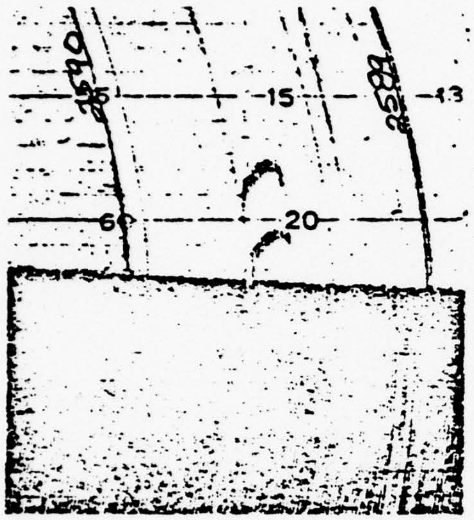


Figure 14. Target Traces, Line 7
CPA of 7 meters

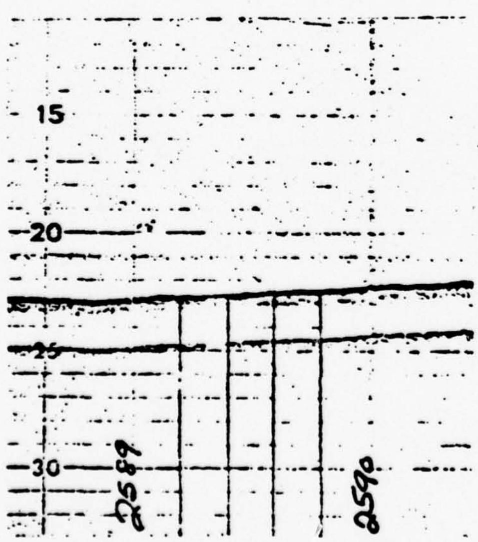


← target 1

← target 2

← target 3
masked by spherical
spreading

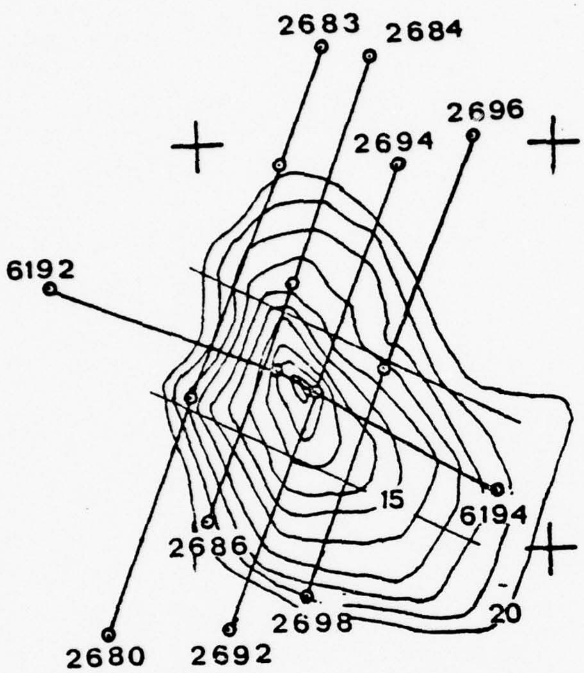
25 by 60 degree beam



← no returns

7 and 22 degree beams

Figure 15. Target Traces, Line 4.
CPA of 20 meters



one fathom contours
7 degree beam
correctors applied

Scale 1:5000

Figure 16. Position Plot (45 meter line spacing)
Top Portion of Eleven Fathom Peak
from Northeast Corner of Area Two

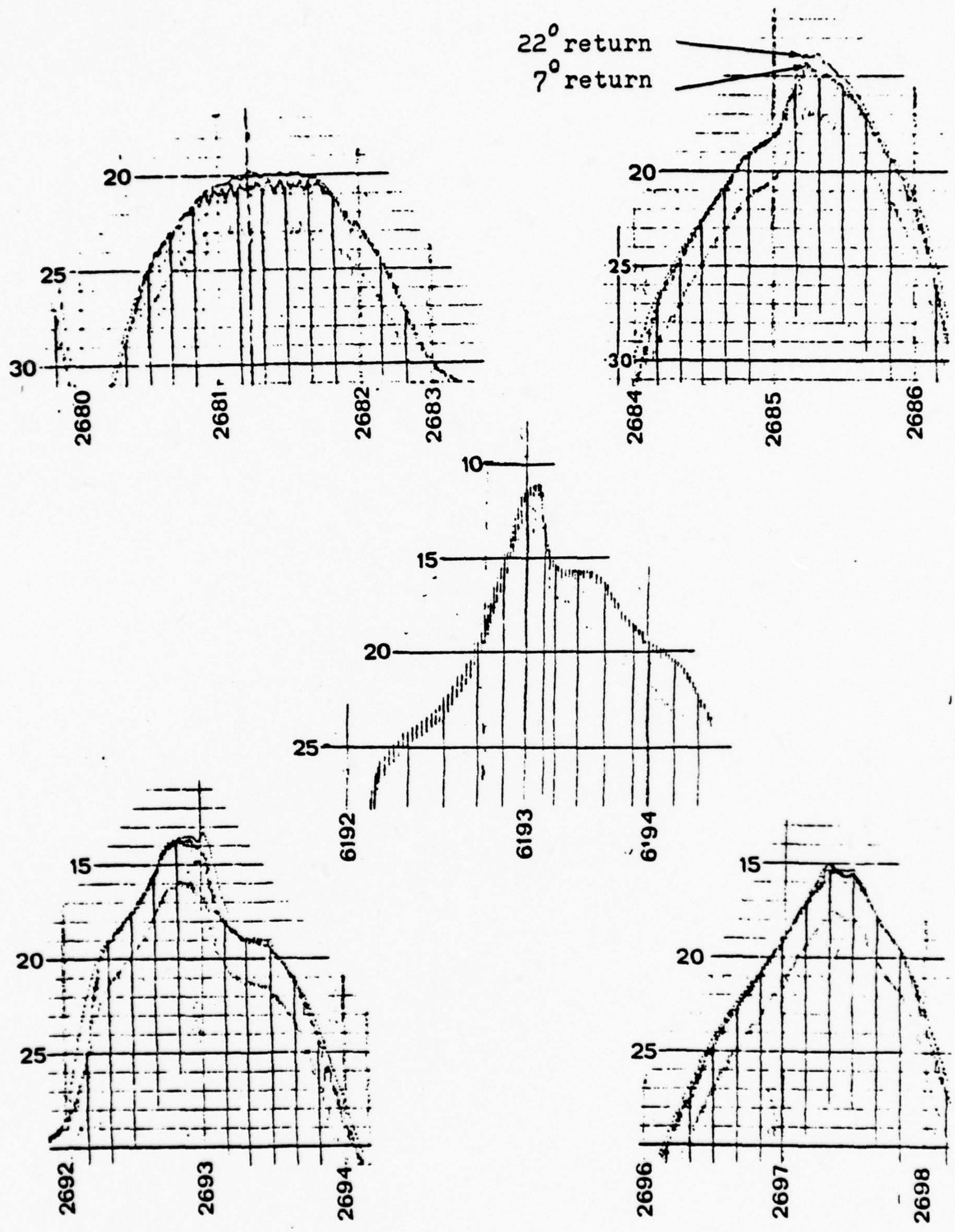


Figure 17. 7 and 22 Degree Beam Sounding Profiles

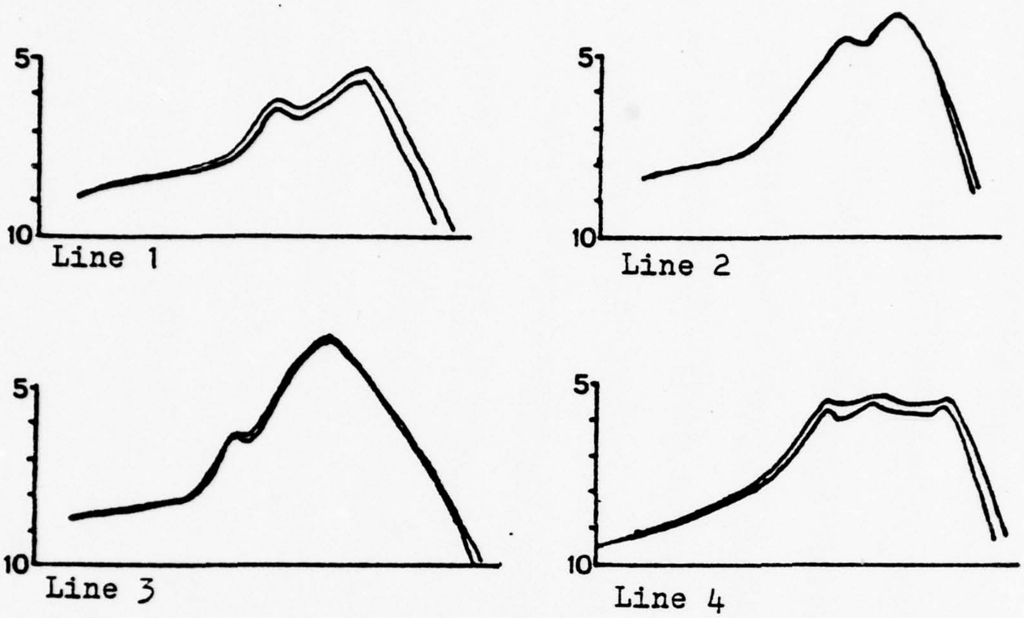
of Area Two. Each of the dual beam profiles has a difference, narrow versus wide, indicating shoaler depths. Sounding line 2692-2694 gave an indication of where to look for the apex of the peak. Line 6192-6194 is three fathoms shoaler. Unfortunately, line 6192-6194 happened to be run by a narrow beam only launch.

Figure 18 illustrates a broad three fathom deep peak from Area One, with sounding lines at twenty meter spacings. The dual sounding profiles are from the seven degree beam, and the twenty-five by sixty degree beam. In this case, the peak is not very well isolated by narrow versus wide depth differences. Sounding lines numbered Two and Three contain little indications of slope. The three to four fathoms water has reduced the bottom coverage and the effectiveness of the dual beam system.

2. Small-Scale Features

The usefulness of a narrow versus wide beam sounding system is more apparent in the following figures of the profiles over features with horizontal extent less than fifty meters. The potential for large slope angles is naturally greater with small features of any significance, and the area of "zero difference" over the peak is small.

Figure 19 shows a small, three fathom peak approximately centered between two twenty meter line spacing sounding lines. At this depth the sixty degree beam was supplying nearly one hundred per cent coverage. The narrow beam did not see the feature.



7 Degree and 25 by 60 Degree Beam Sounding Profiles
Depths in Fathoms

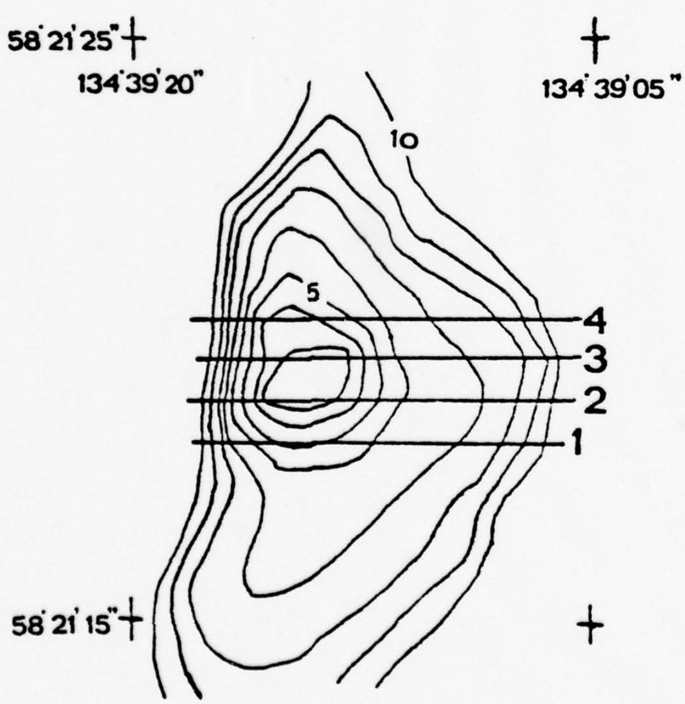


Figure 18. Top Portion of Three Fathom Peak
from Area One

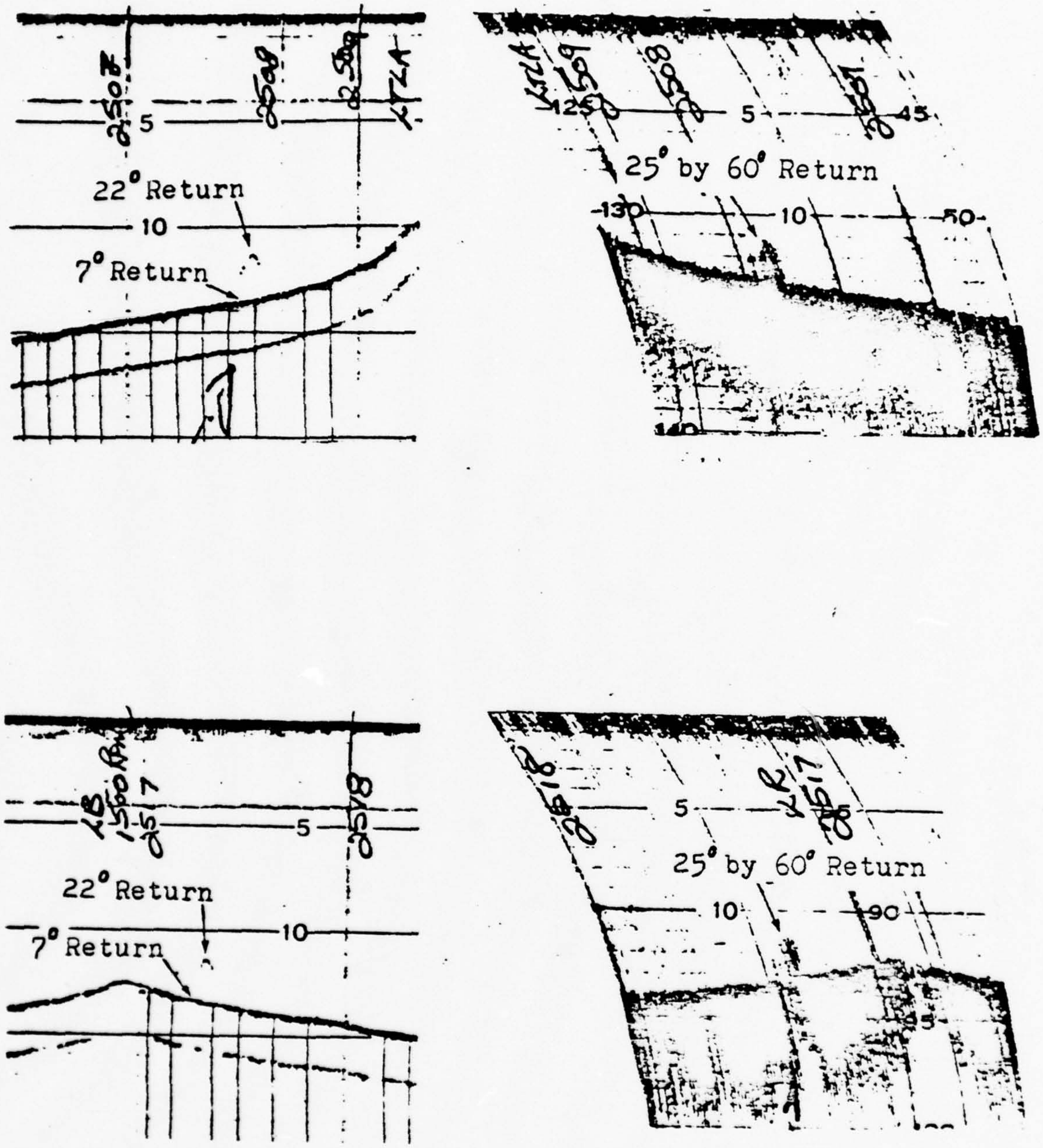


Figure 19. Small three fathom Peak, between two twenty meter line spacing Sounding Lines

Figure 20 illustrates that even in five to ten fathom water, the narrow versus wide beam data may be useful in locating and determining the least depth of small features. The bottom coverage was very limited (22 beam = 4 meters), but narrow versus wide depth differences are visible on line 2 and in line 3 on the steep slopes of the small peak.

Figure 21 indicates a wide beam return. The wider hyperbolas of the wide beams strongly substantiate the narrow beam returns, which might have missed the scanner's attention. When surveying at speeds between eight and fifteen knots, the narrow beam was transmitting at intervals of seven to thirteen feet. Therefore, features of substantial height and horizontal extent may be indicated by only a couple of narrow beam marks on the analog trace. These isolated narrow beam marks may easily be mistaken as "strays." The wide beam extends the small scale feature returns to a point where they are more difficult to ignore. The difference in narrow versus wide depths at the peak apex indicates this was not the peak's least depth.

C. PRIMARY FACTORS

1. Peak Detection

Evaluating the benefits of increased bottom coverage by using a wide beam is generally difficult to quantify because of the problem of spherical spreading and its dependence on water depth. The detection of features between sounding lines which were not indicated by the narrow beam would be such a measure. Isolated small scale features similar to

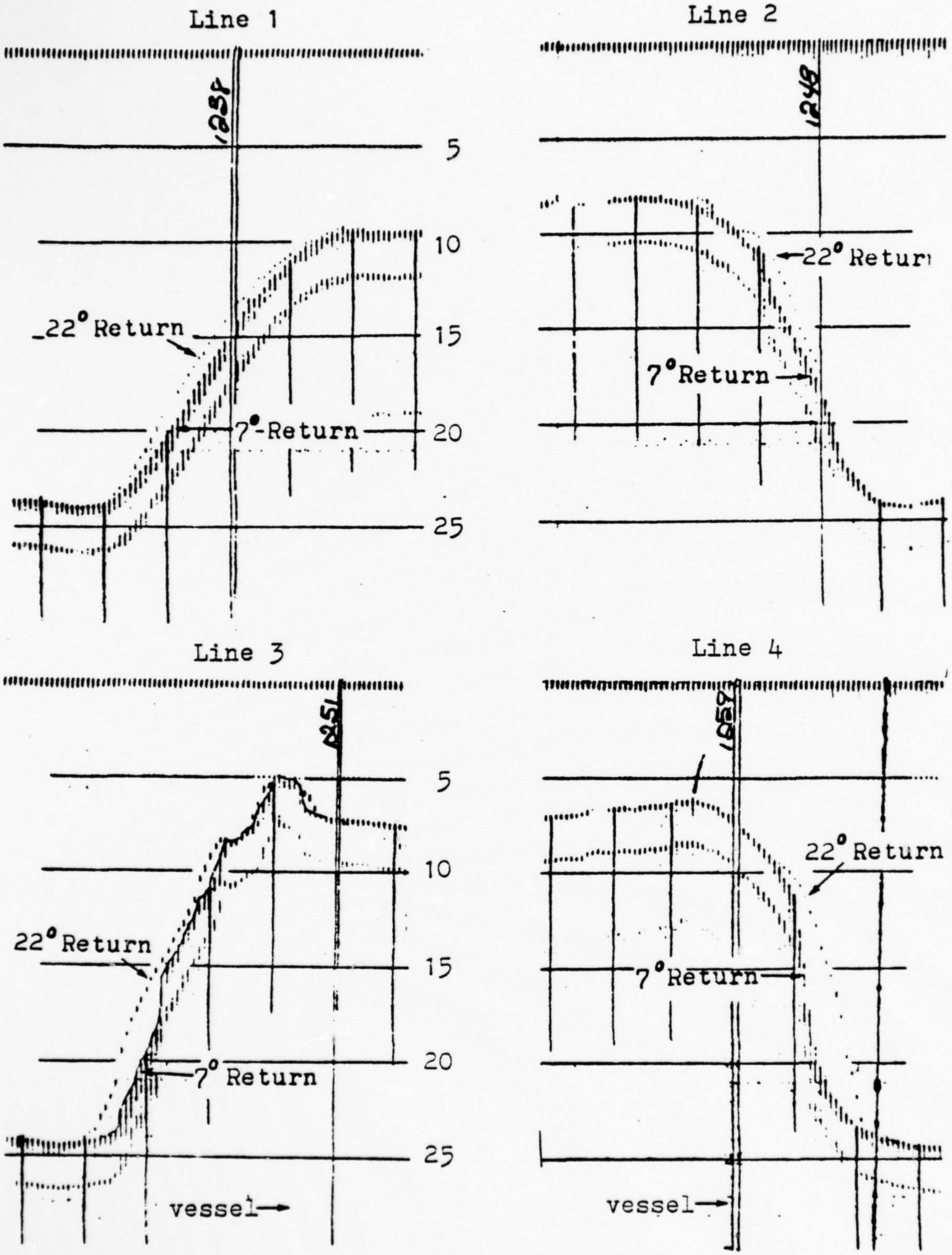


Figure 20. Twenty meter line spacing, East-West, Sounding Lines across two fathom Peak of about twenty meter Extent

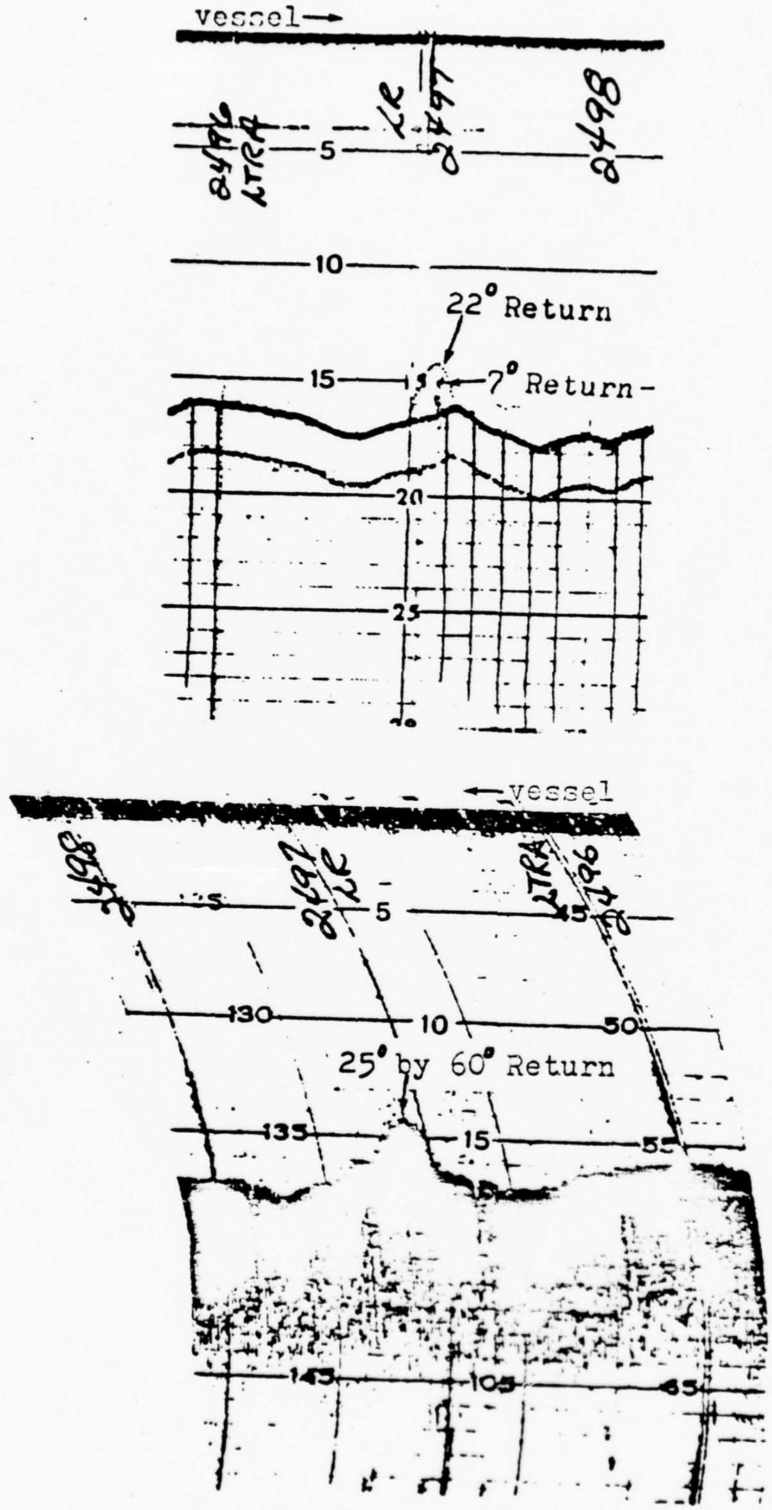


Figure 21. Various Beam Width Returns from a North-South Sounding Line adjacent to a three fathom Peak

those in Figures 19, 20, and 21 were disappointingly scarce. The narrow beam analogs contained three isolated peaks of less than fifty meter horizontal extent and of any significant height. The wide beams reflected five isolated small scale peaks that were not recorded by the narrow beam trace. Figure 19 was one of a group of three small scale peaks that were two to three fathoms high and less than twenty meters in extent in a fairly flat area (58°21'15"W, 134°38'52"N, Area One) of ten to fifteen fathoms deep. These peaks were developed by a second set of north-south sounding lines at twenty meter spacing and were still not picked up on the narrow beam trace.

The sample size is too small to make any quantitative estimate of the wide beam's potential to reflect features totally absent on the narrow beam trace. The feature discoveries that could be attributed solely to the wide beam's side-looking abilities were a significant number because the total dual beams' hydrography amounted to only sixty nautical miles or one typical launch working day.

The average launch speed was eight knots, or about four meters per second. The pulse repetition rate at this speed was fast enough to supply overlapping insonified bottom areas for the wide beams, up to a depth of two or three fathoms. The seven degree beam began to lose overlapping areas in depths less than nine fathoms due to its smaller insonified bottom area. The wide beam of a dual beam system decreases the problem of maintaining overlap between pulses in very shallow water.

2. Peak Isolation

The narrow versus wide beam depth differences may assist the hydrographer by indicating the sounding line has passed within some limits of the peak's apex. The difference between the narrow and wide beam depths goes to zero over the peak apex. The least depth would have to come from the narrow beam trace in order to maintain positional accuracy, unless the water was very shallow. The previously presented profiles over individual features demonstrated cases where the sounding line obviously did not find a least depth as well as cases where the sounding line displayed a "zero difference" and must have crossed near the apex. Theoretically a "zero difference" while developing a feature would be a point directly over the least depth. The resolution of the echo sounder limits the minimum depth difference that is discernible before it is considered zero.

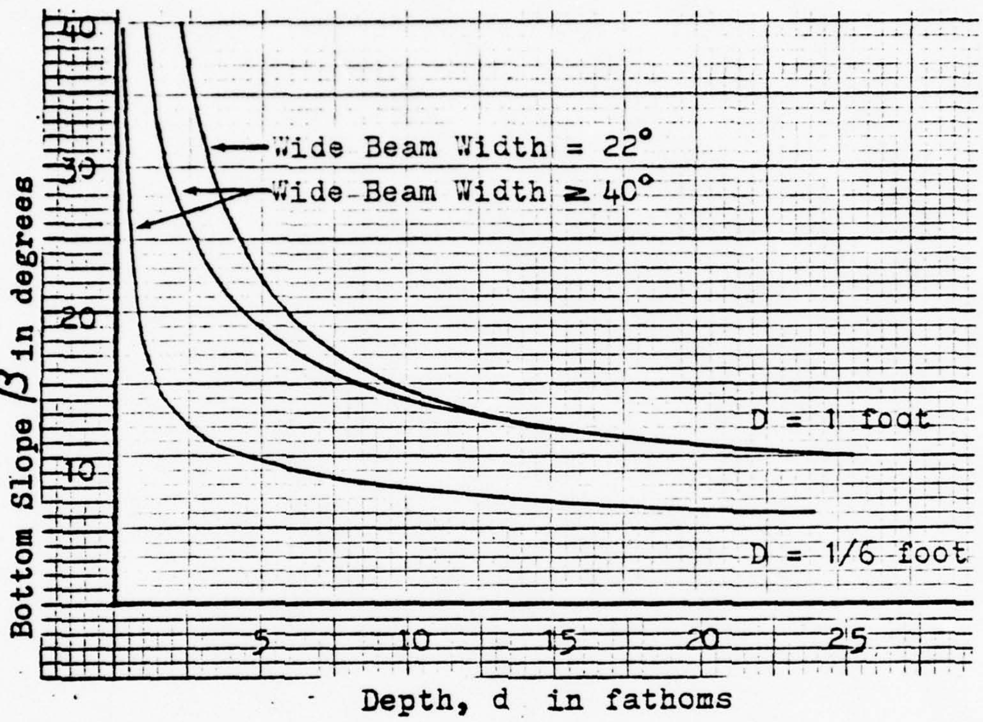
For the seven and twenty-two degree system used in this project, a one foot difference in narrow versus wide beam depths was visible while using the fathom scale. This resolution is not considered overly optimistic when both narrow and wide beam traces are on the same recorder. The timing errors will affect both the traces equally when they are on the same recorder. A small difference in the wide and narrow beam traces is readily discernible if the wide beam directly overlays the narrow beam trace, and if it is recorded with a lighter mark intensity.

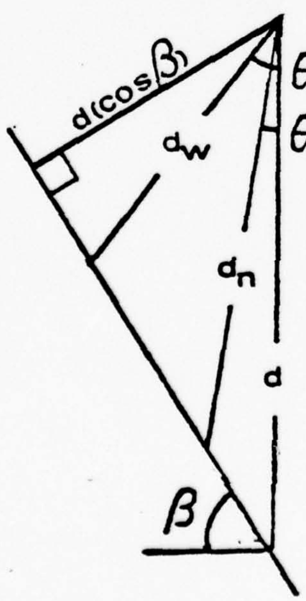
The minimum bottom slope required at a particular depth to generate a one foot difference between the seven degree beam and the twenty-two degree beam is plotted in Figure 22. Features with slopes and depths that plot above this curve will have some degree of peak isolation using narrow and wide beam depth differences. Also plotted is the dividing line for a forty degree wide beam with minimum discernible depth differences of one foot. The minimum discernible depth difference could have been decreased to one-sixth foot by operating the system using the feet scale.

The one foot dividing line for features that will develop narrow versus wide beam depth differences and allow some degree of peak isolation agrees with the project data. For example, Figure 17 has fifteen to twenty degree slopes and depths of ten to fifteen fathoms near the peak. Sounding lines adjacent to the peak indicate that the apex was not found. Figure 18 has slopes averaging about ten degrees and depths of two to five fathoms, which is below the useful peak isolation line. The large scale features had average bottom slopes across their apex in the five to fifteen degree range. The significant small scale features typically had slopes greater than twenty degrees, which requires depths of at least four fathoms for peak isolation.

Assuming cone shaped features, the degree of peak isolation has been plotted in Figure 28. This illustrates

Figure 22. Bottom Slope and Depth to obtain minimum *Depth Difference* of 1 Foot and 1/6 Foot between the Narrow and Wide Beams





D = minimum discernable difference narrow versus wide depths

$d_n = d \cos\beta/\cos(\beta-\theta_n)$

$d_w = d.\cos\beta/\cos(\beta-\theta_w)$

$D = d_n - d_w$

d_w = wide beam depth

d_n = narrow beam depth

β = bottom slope

θ_n = 1/2 angle narrow beam =

θ_w = 1/2 angle wide beam

d = true depth

the diameter of the circular area of "zero difference" over the cone shaped feature for a seven degree narrow beam versus a wide beam of at least forty degrees. The features on this figure are plotted against peak depth. Figure 23 illustrates the peak isolation limits for a minimum discernible difference of one foot.

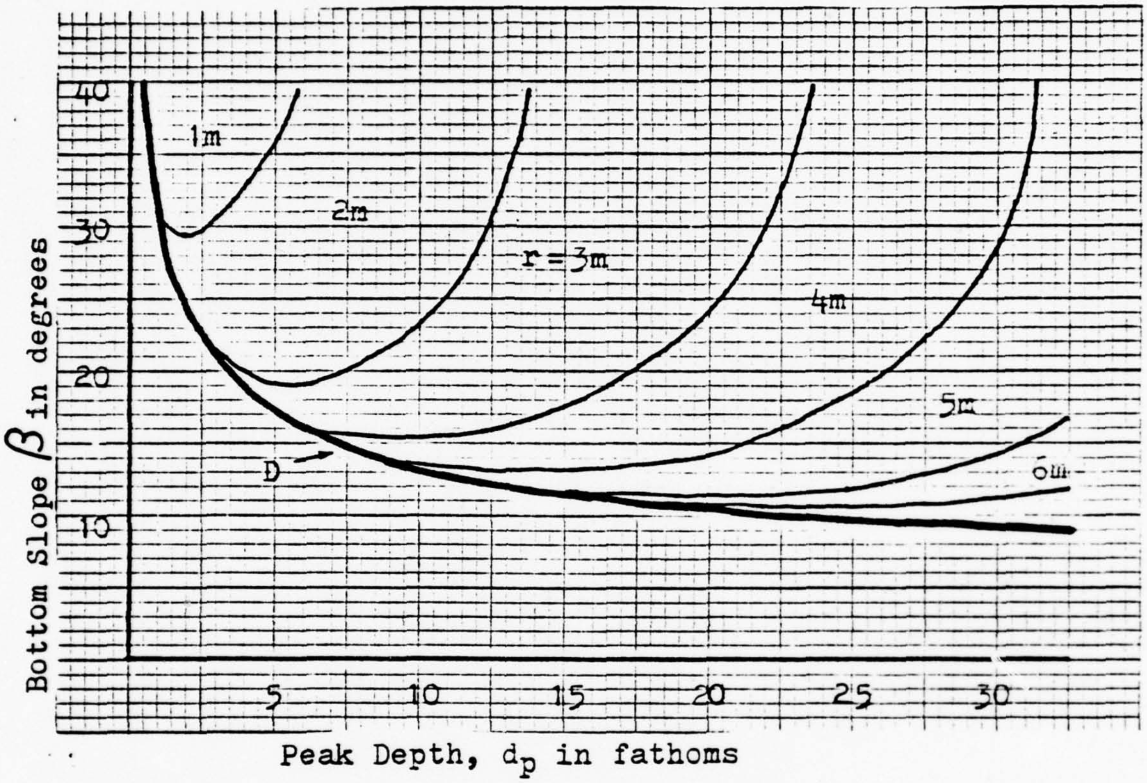
The narrow versus wide beam depth difference can assist the hydrographer in isolating and determining a least depth. The feature to be developed may be run, using a line spacing based on a reasonable wide beam's bottom coverage. For example, the spherical spreading of a thirty degree beam is not excessive. A thirty degree beam will indicate shoals within its insonified area that are greater than five percent of the vertical depth. Also, the thirty degree beam has an insonified area that is still five meters in diameter, in only five fathoms of water (Figure 5). The narrow versus wide beam depth differences will isolate the features peak to a degree that, if necessary, is more reasonable to further develop using only the narrow beam.

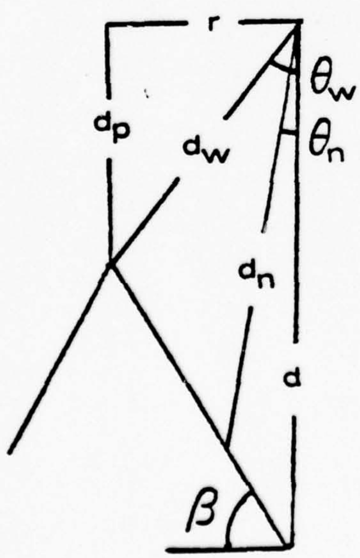
D. SECONDARY FACTORS

1. Wide Beam Depth Error

Features substantially larger than the line spacing were common in the work areas. The bottom slopes of these large scale features averaged eighteen degrees, with a few maximum slopes of about forty degrees. These slopes naturally generated the most extensive differences in recorded depths

Figure 23. Peak Isolation for Cone Shaped Features





D = minimum discernable difference narrow versus wide depths 1/6 fathom

r = radius of peak isolation area in meters

d = true depth

d_p = peak depth

d_w = wide beam depth

d_n = narrow beam depth

β = bottom slope

θ_n = 1/2 angle narrow beam

θ_w = 1/2 angle wide beam

between the various beam widths. The depth differences are illustrated in Figures 24, 25, 26 and 27. The fine lined contours were generated from the narrow beam corrected depths. The fine line contours may be considered very nearly the true depths and actual feature shapes. The bold contours are the differences obtained between the wide beams and the seven degree narrow beam. The bold contours are the depth errors created by the wide beam echo sounder, relative to the narrow beam echo sounder. For example, in Area One, there is a central north-south trending ridge. The western slope at the northern end of the ridge had the maximum bottom slopes ($\cong 45°$) for the area. The twenty-two degree beam and the sixty degree wide beam recorded depths two fathoms and four fathoms shoaler than the narrow beam depths.

The depth differences obtained from the three beam widths generally agreed within one half fathom to computed values for respective bottom slopes. The computed difference may be derived from the following relations:

a. Bottom Slopes Less than One Half the Wide Beam Width $D = d_n(1 - \cos(\beta - \theta_n))$.

b. Bottom Slopes Greater than One Half the Wide Beam Width $D = d_n(1 - \cos(\beta - \theta_n)/\cos(\beta - \theta_w))$

D = Depth Difference for Wide versus Narrow Beams

θ_w = One Half Wide Beam Width

d_n = Recorded Narrow Beam Depth

β = Bottom Slope Angle

θ_n = One Half Narrow Beam Width

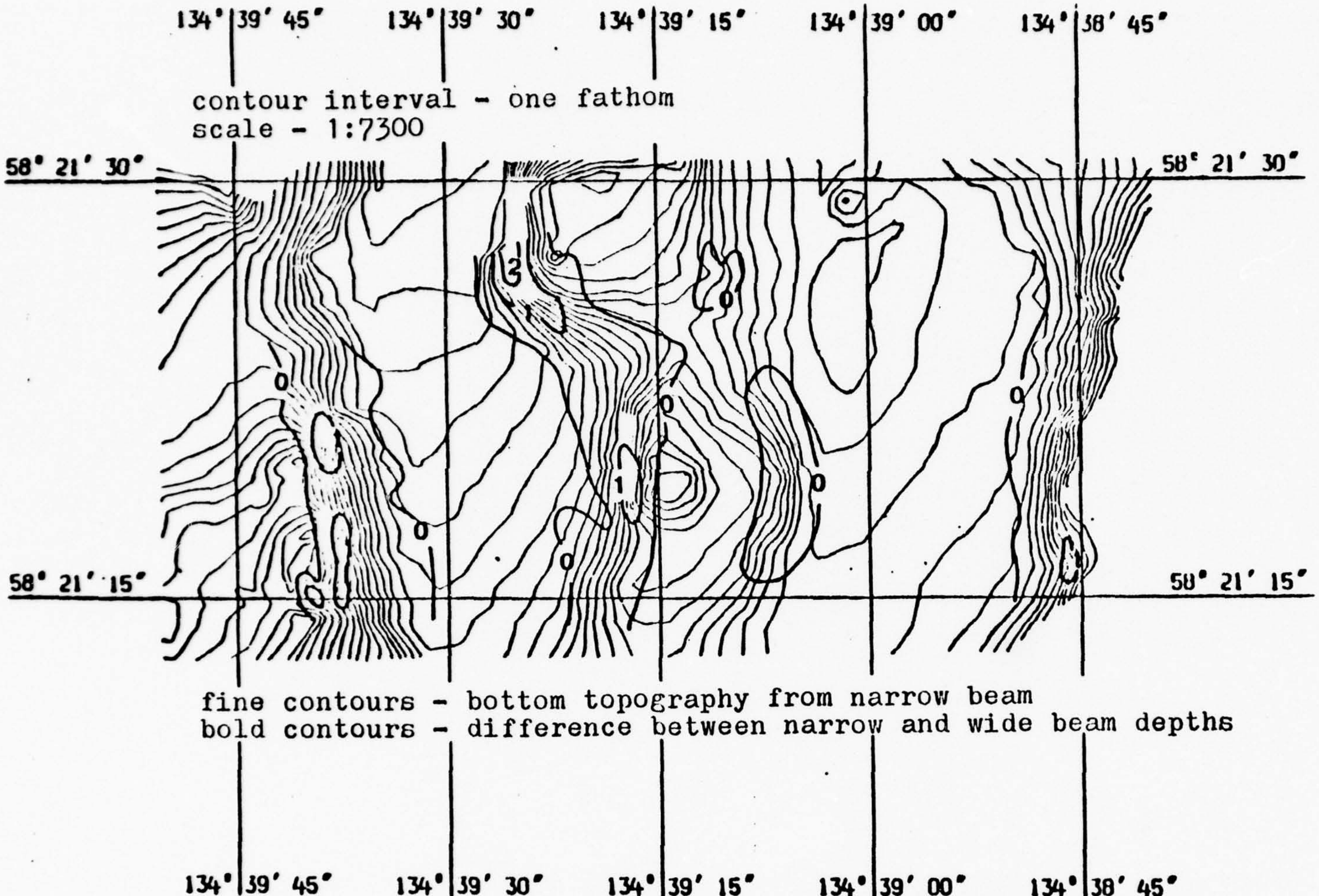


Figure 24. 7 degree versus 22 degree Beam Width Depths
Area One

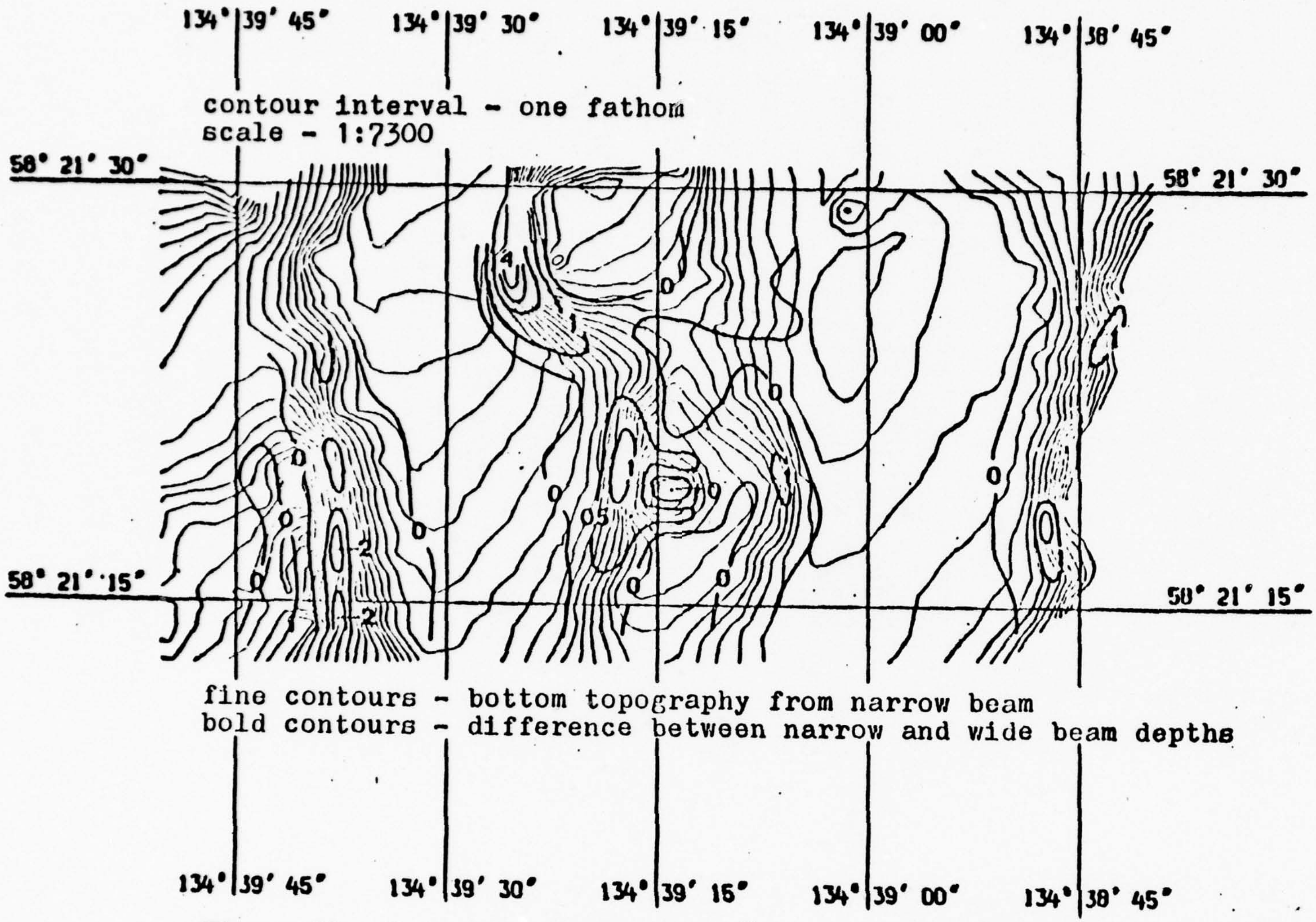


Figure 25. 7 degree versus 25 by 60 degree Beam Width Depths Area One

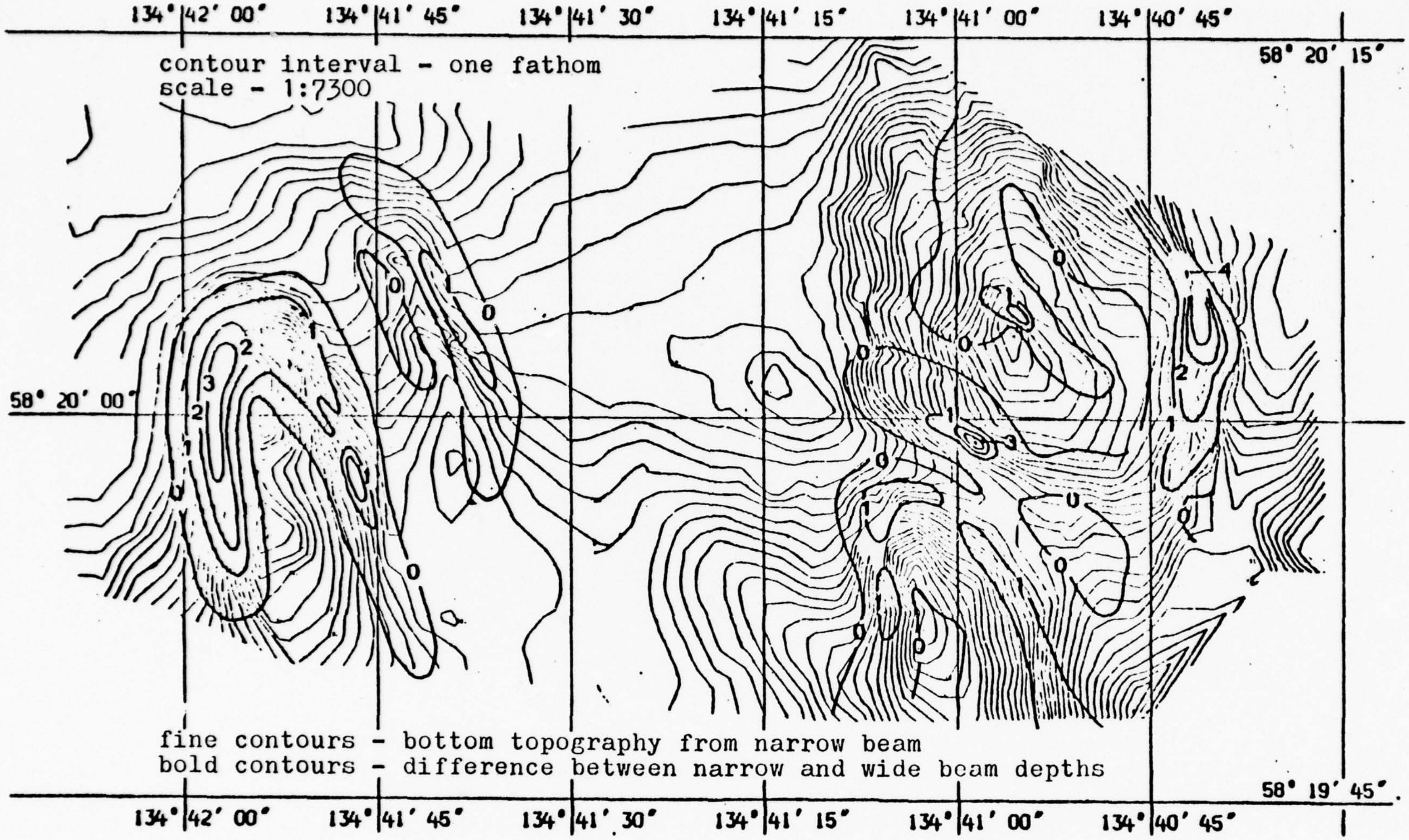


Figure 26. 7 degree versus 22 degree Beam Width Depths
Area Two

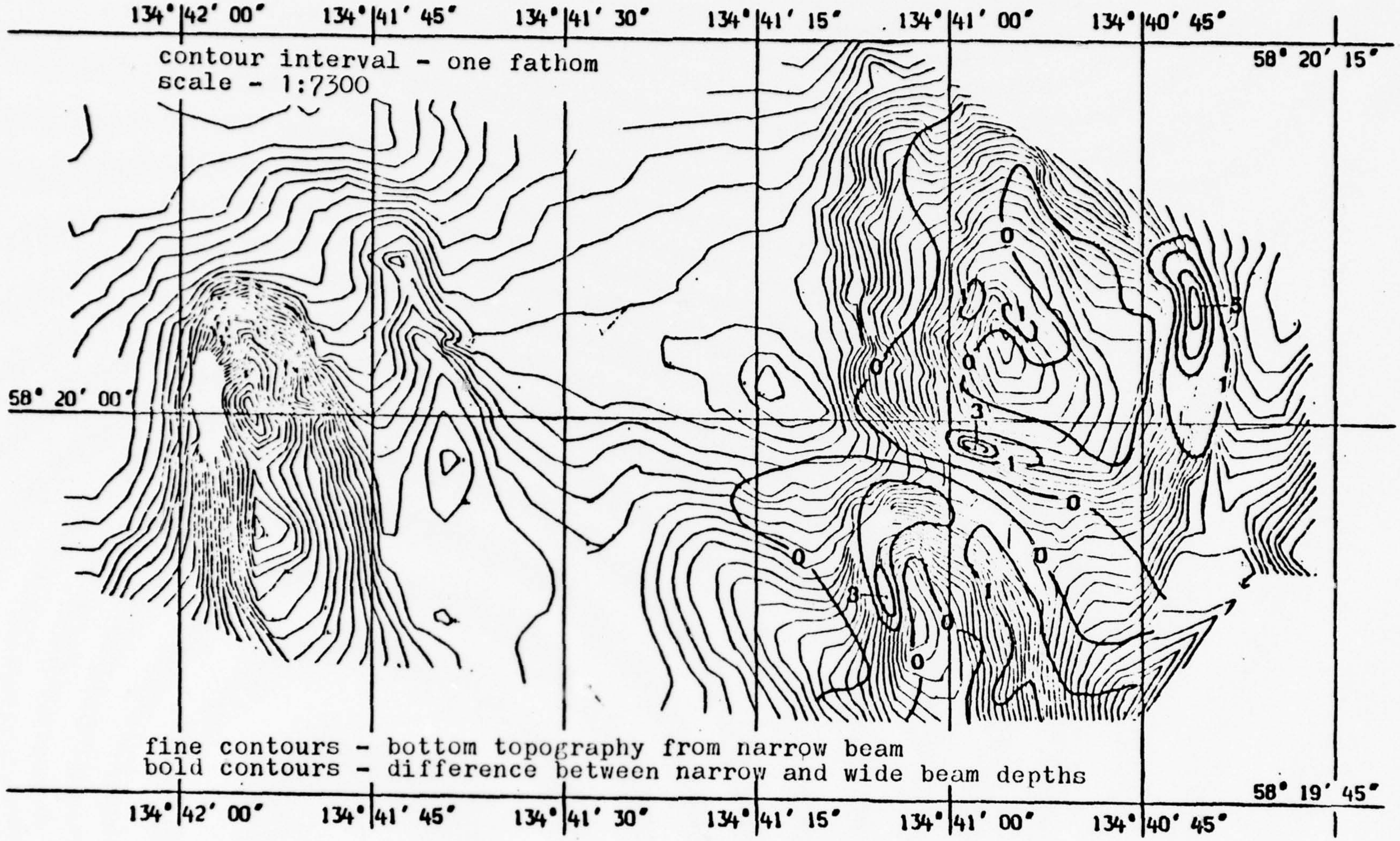


Figure 27. 7 degree versus 25 by 60 degree Beam Width Depths
Area Two

The twenty-five degree, fore and aft, by sixty degree athwart-ship rectangular beam should show maximum differences on slopes tangent to the vessel track, and very little difference on slopes normal to the vessel track, in comparison to the twenty-two degree conical beam. This is apparent in the east-west elongation of the features of Area Two.

The figures illustrate the substantial depth error obtained by the wide beam echo sounder in relatively shallow water, and is a consideration when using prior surveys in comparison with current surveys. The positional errors of the depths recorded by the wide beam system in areas of sloping bottom averaged roughly five to seven meters. The maximum shift in position of the contours is simply limited by the echo sounder's beam width and depth ($d \sin \theta \cos \theta$). The measured shifts in contour position, due to the wide beams, agree, to within a few meters, with the computed values for the working area depths. The shifts were only a few meters greater than the vessel's positional accuracies, but only because of the water depth. In one hundred fathoms a twenty-two degree echo sounder may cause thirty-five meter shifts in contour position. The requirements for the resolution and positional accuracy of a reasonably narrow beam echo sounder is unquestionable.

Figures 24, 25, 26 and 27 indicate to some degree the usefulness of the wide beam to the hydrographer on large scale features. The extent to which the difference contours surround the apex of individual peaks, and the size of the "zero difference" area over the peaks, is indicative of the ability of the concurrent sounding system to isolate the apexes. In most cases the diameter of the area of "zero difference" in recorded depth between narrow and wide beams was larger than a 1:5,000 scale fifty meter sounding line spacing, so the hydrographer has gained little. These large features shoaled to around five fathoms. At five fathoms the insonified area is limited (see Figure 5), and a substantial bottom slope is required to overcome the curvature in the wide beam.

For example, the individual peaks on the north-south trending ridge in the southwest corner of Area One were not isolated by narrow versus wide depth differences of the east-west sounding lines.

Figures 24, 25, 26 and 27 were generated from soundings at the six to eight second sounding interval, and present a generalized picture of the broad features.

2. Pitch and Roll Error

The dual beam system was considered during project design as a means to preserve some indication of sea state on the analog records, due to the difference in reaction to pointing error of the narrow versus wide beams. The heave, pitch, and roll error cannot be reliably identified from bottom topography subsequent to the field work, unless the records were annotated for sea condition.

The seas during the project were very calm, except for the last day, which had a three foot chop. The difference of the narrow versus wide beam depths, due to vessel pitch and roll, was too similar to the result that would occur due to the difference in horizontal beam resolution for this characteristic to serve as an indicator of sounding in rough water. In both cases the small scale periodic variations in the narrow beam trace are smoother in the wide beam trace. The top left corner profile of Figure 17 shows narrow beam depth variations known to be caused by roll, while sounding on a sloping bottom. The wide beam maintained a nearly flat trace. Assuming these narrow beam variations were actual bottom features, the narrow and wide profiles would be expected to appear the same, due to the wide beam's poor horizontal resolution.

3. Bottom Type

The predominance of high frequency narrow beam systems has resulted in the loss of possible useful geological information derived from the lower frequency's (Watt, 1977). A recent concern is the possibility of an upper layer composed of a "slurry," with sound velocity equal or less than that in the water column. This may be detected with dual frequency systems.

Bottom samples were obtained by the NOAA Ship RAINIER, adjacent to the project areas, during the course of their hydrographic survey. The bottom composition was fairly uniform, and consisted primarily of silt and clay with rock outcrops. The 21 kHz low frequency analogs were carefully compared with 100 kHz high frequency analogs in the flat bottom areas for low frequency depths greater than high frequency depths, which would indicate a "slurry." The relative depths remained equal. Also, very little useful penetration was exhibited by the 21 kHz system, indicating a fairly consolidated bottom.

4. Back Scattering

The Auke Bay area has repeated plankton blooms in the spring and early summer. A bloom was occurring during the last few days of this project, which had a marked effect on the echo sounder's ability to maintain a bottom trace. No attempt was made to obtain a biological sample of the zooplankton responsible. But the problem with the traces occurred in patches that correlated with the density of phytoplankton visible from the surface. The plankton's scattering effects were greater for the 21 kHz system, to such a degree that in some areas a bottom trace could not be obtained. This problem illustrates the frequency dependence on biological scattering and an additional possible benefit of a dual frequency system. The majority of the project's data was obtained before the plankton became a problem.

5. Minimum Depth

The minimum depth obtainable with an echo sounder is related to the pulse length and the resulting initial reverberation. In very shallow water the bottom return becomes lost in the initial reverberation. The 21 kHz and 100 kHz systems have pulse lengths of .009 seconds and .001 seconds, respectively. As expected, the 21 kHz trace was periodically lost in the initial reverberation while maneuvering in shallow water. But interestingly, the 21 kHz system was equally useful in very shallow water with the transducer mounted on a strut along the starboard side. The narrow beam trace, with its transducer mounted near the keel, was repeatedly lost in the propeller wash while maneuvering inshore to start an off-shore line. The difference was probably due to transducer location, rather than frequency, penetration and backscatter. In a dual beam system for launch hydrography, it may be useful to mount the wide beam transducer away from the keel on a fairly flat-bottomed launch.

V. CONCLUSIONS

The negative effects of the wide beam's poor horizontal resolution and the degree of wide beam depth error relative to a seven degree narrow beam were plotted for the two project areas. The plots illustrate the necessity of a narrow beam echo sounder for accurate depth determinations. The results confirm the usefulness of side-looking abilities of the wide beam echo sounder, in spite of the problems with spherical spreading. The sample size of the features detected with the wide beams was too small to quantify the usefulness of the sixty degree transverse beam relative to the twenty-two degree beam. The wide beam trace was found to emphasize the narrow beam profiles over small features that may have missed detection when scanned.

A useful ability of peak isolation is exhibited by the narrow versus wide beam depths over feature peaks. This requires a visible narrow versus wide beam depth difference in the recorded traces near the peak's apex, which is a function of the bottom slope and peak depth. A model using cone shaped features indicates the degree of peak isolation.

A number of desirable dual beam design concepts for use with hydrographic surveying were obtained. The wide beam and narrow beam trace should be displayed on the same recorder. This reduces the relative, narrow versus wide beam, time error, and allows for easy visual comparison. The narrow and wide beam trace should be set to directly overlap. This allows small depth differences to be readily discernible. The small depth differences between the narrow and wide beam were significant over the peak apexes, and determined the degree of peak isolation. Separate gain and mark sensitivity controls are required to maintain a distinct difference in the narrow and wide beam returns. The necessity of a difference in operating frequencies, for the narrow and wide beams, was confirmed for concurrent sounding with dual beams. The study's seven and twenty-two degree beams both operated at 100 kHz. This caused interactions between transducers and problems in interpreting the results.

The dual beam echo sounder appears to be well-suited for filling the void between narrow beam sounding and swath or scanning sounding systems in shallow water launch hydrography. The abilities and procedures with narrow beam echo sounding are maintained, while the beneficial factors inherent in a wide beam system are added. The wide beam trace becomes a familiar and easy to operate descriptive tool for the hydrographer

APPENDIX A

A. EXCESS SIGNAL LEVEL FOR SEVEN DEGREE BEAM TRANSMIT AND TWENTY-TWO DEGREE RETURN

The recorder analog traces showed both seven and twenty-two degree characters when the audio lines were combined to the recorder. The following computation shows the beam pattern and possible excess echo levels for a seven degree transmit and twenty-two degree return. The result illustrates a feasible origin for the wide return for the seven degree transmitted analog trace.

Assuming a specular return from the bottom the sound pressure at the receiver appears to arrive from a mirror image source constructed across the bottom interface. The sound pressure at the image source equals the pressure at the original source times a factor for bottom losses, the reflection coefficient. The excess echo level is equal to the difference in propagation losses for the shallow water case and the maximum operating range. Assuming the same bottom reflection coefficient the propagation losses will be due to spherical spreading and attenuation in the water column over twice the range.

Excess Echo Level = Propagation loss 200 fathoms - Propagation loss 30 fathoms

$$\text{Excess Echo Level} = 20 \log 2R + \alpha 2R - 20 \log 2r - \alpha 2r$$
$$= 20 \log R/r + 2\alpha(R-r)$$
$$16.5 + 20.4 = 36.9 \text{ dB}$$

R = 200 fathoms (maximum operating range)

r = 30 fathoms (project operating range)

α = .06 dB/fathom

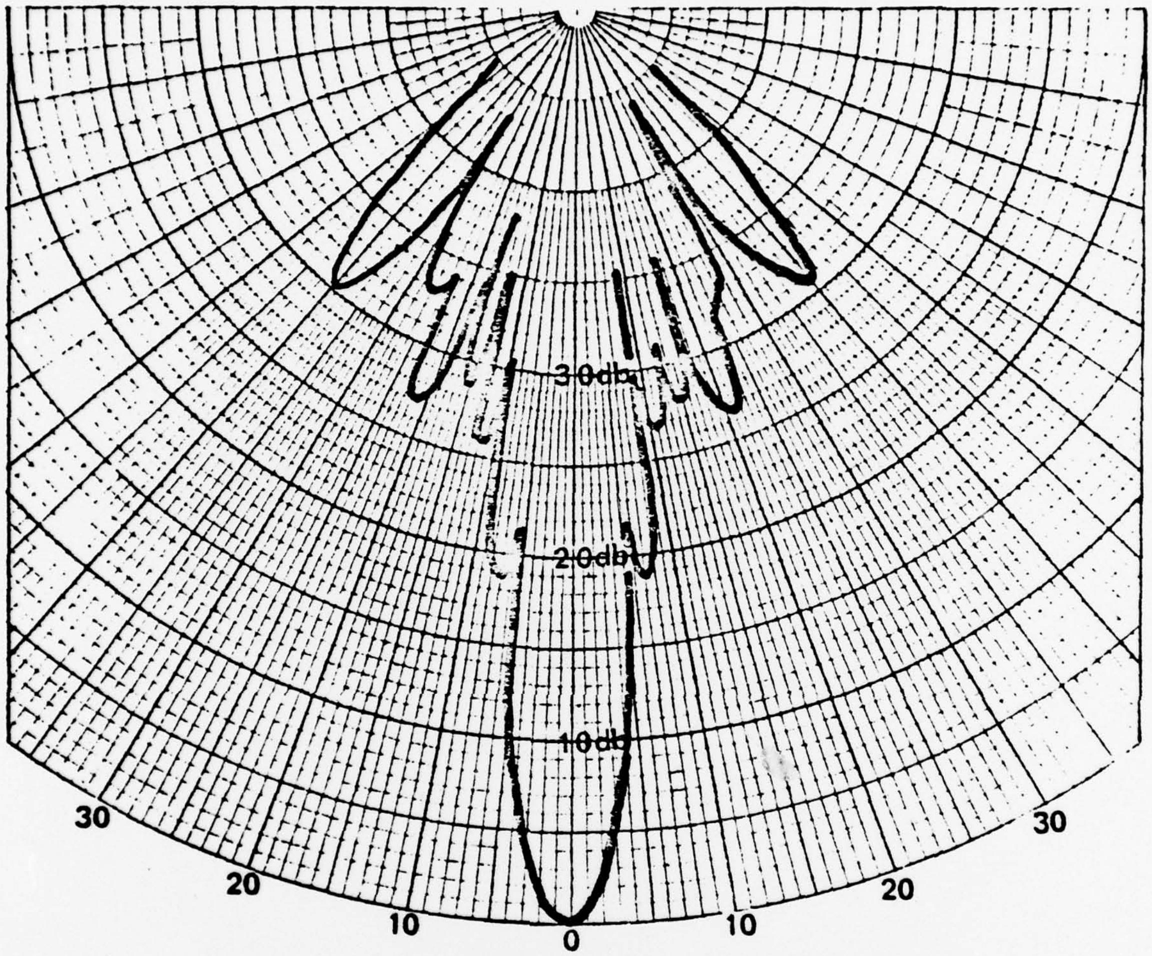


Figure 28. 7 degree Beam Pattern

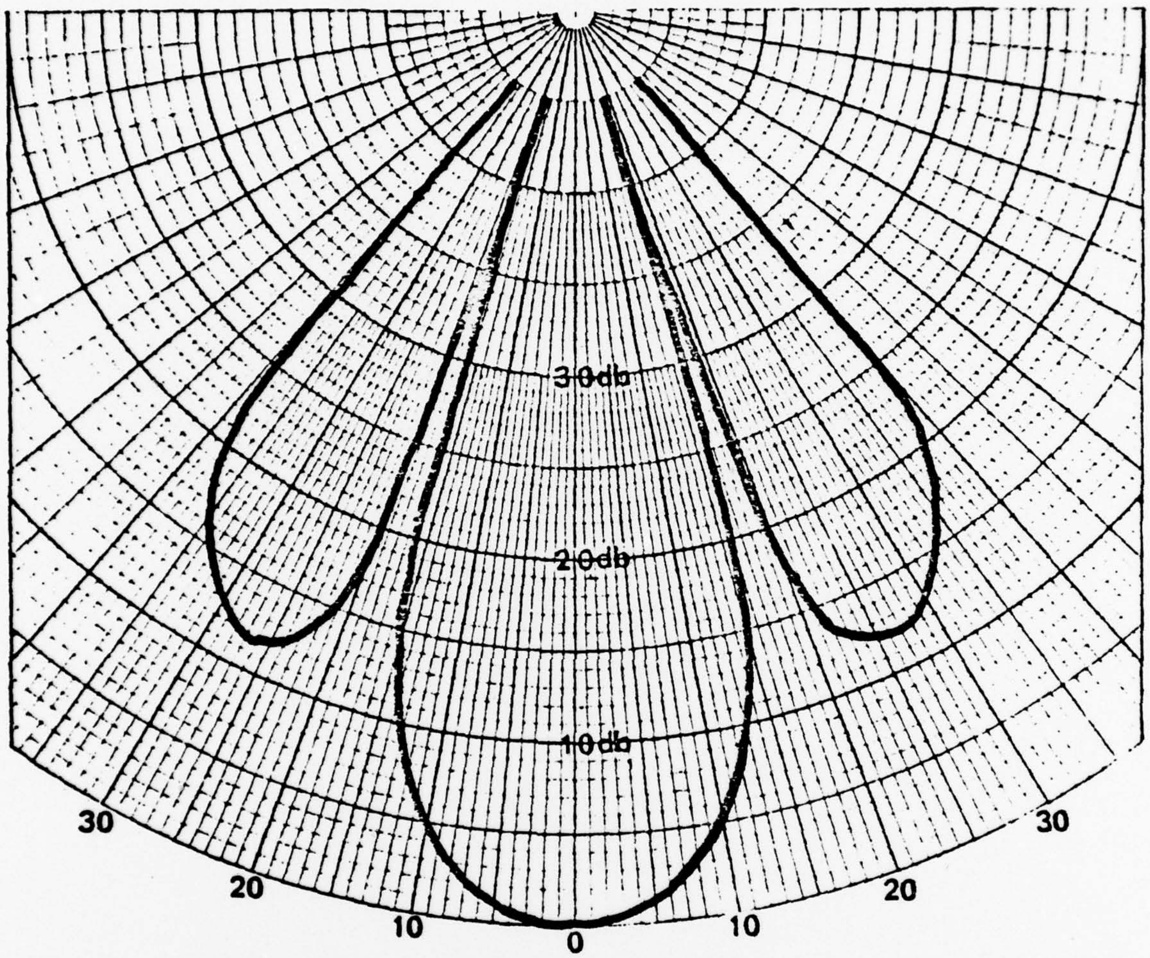


Figure 29. 22 degree Beam Pattern

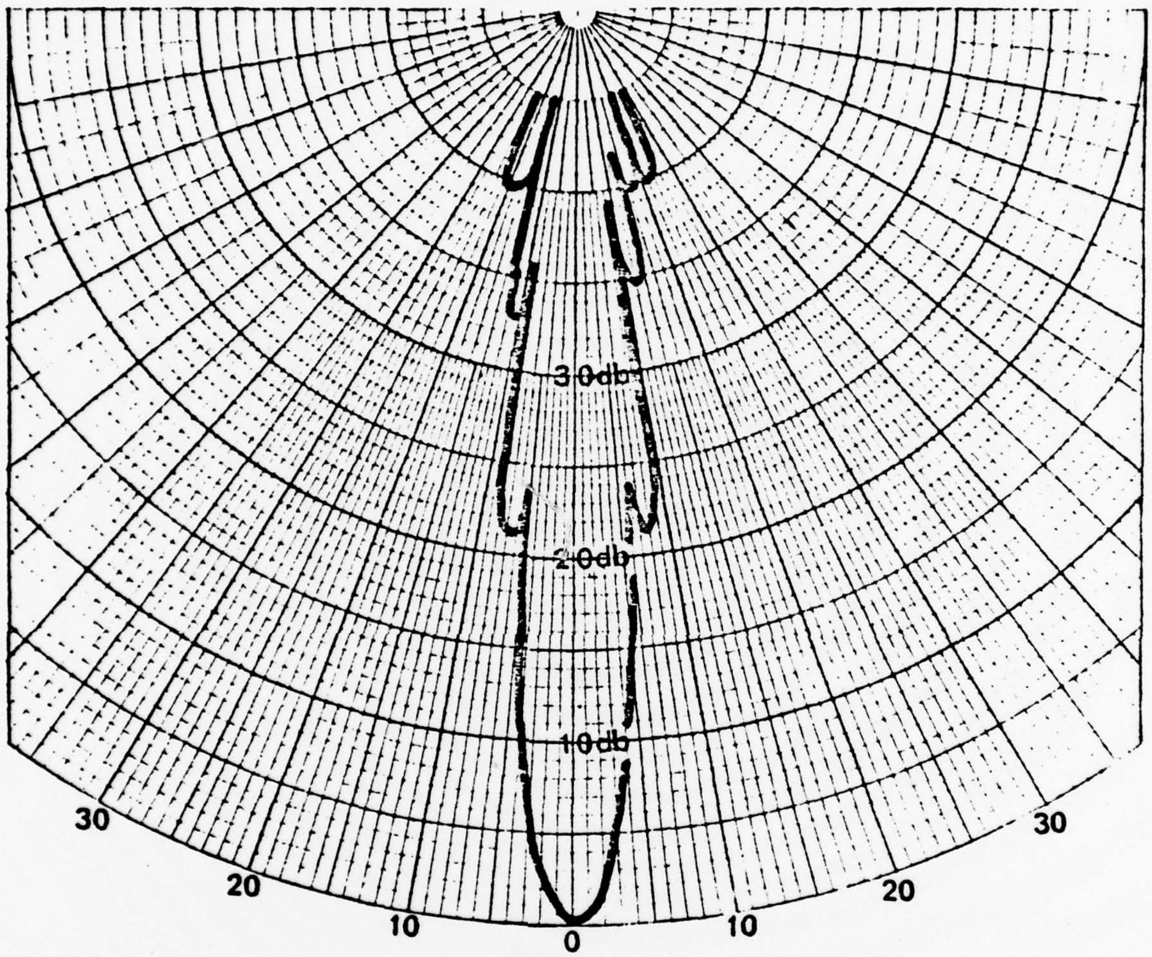


Figure 30. Sum of 7 and 22 degree Beam Patterns

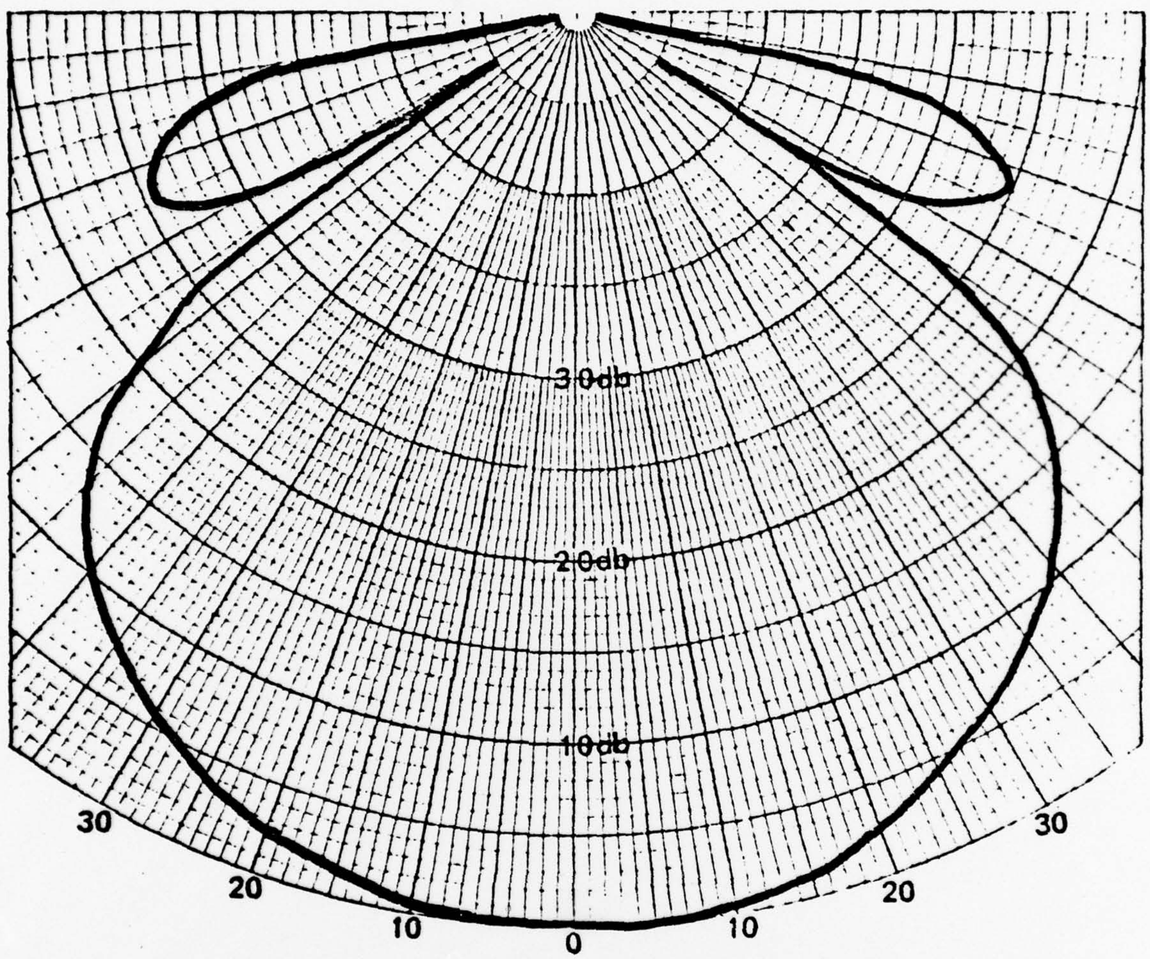


Figure 31. 25 by 60 degree Beam Pattern
60 degree athwartship Pattern

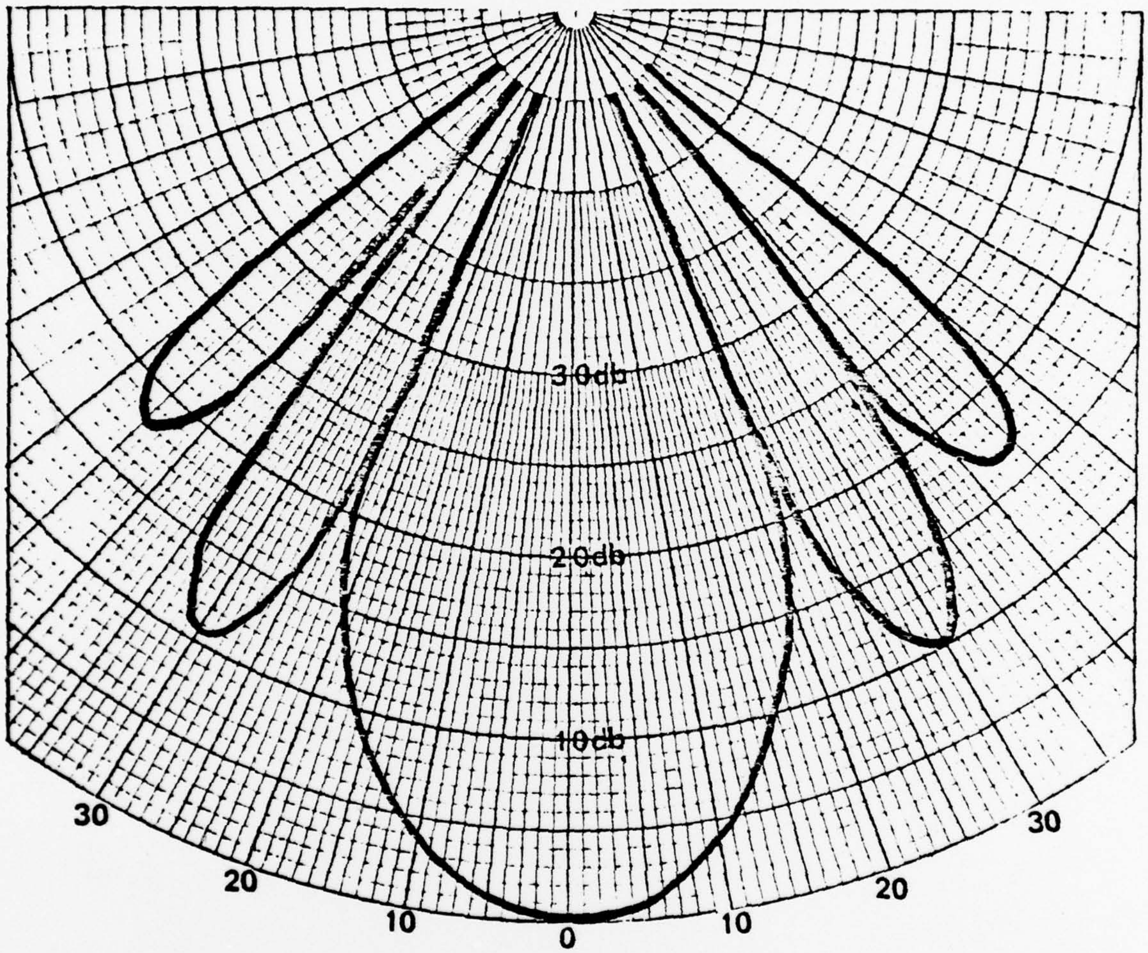


Figure 32. 25 by 60 degree Beam Pattern
25 degree Fore and Aft Pattern

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